Radioactive occurrences and uranium production in Arizona

Part 1 of 3 - digital version
Includes:
Introduction
Uranium occurrences in Arizona
Thorium in Arizona

Final Report

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ABSTRACT

Nine hundred and sixty-five natural radioactive occurrences of uranium, some containing thorium, are known for Arizona. Of these, 328 localities were the source of 18.1 million pounds of U_3O_8 between 1948 and 1970. About 43 million pounds of V_2O_5 were present in the uranium ores. Ninety-nine percent of Arizona's total production is from the Triassic-Jurassic sedimentary rocks of the Colorado Plateau, approximately half of which came from the Salt Wash Member of the Morrison Formation in the Carrizo and Lukachukai Mountains. Historically, only a small amount of uranium has been produced from the Basin and Range Province. However, recent exploration has shown significant uranium potential in late Tertiary sediments in this region.

Arizona's largest single uranium deposit has been at the Monument No. 2 Mine of Apache County. There, about 5.2 million pounds of U_3O_8 and nearly eleven million pounds of V_2O_5 were produced from a single channel deposit in the Shinarump Member of the Triassic Chinle Formation.

Eighteen major groupings of uranium occurrences are recognized in Arizona for the purposes of classifications; eleven on the Colorado Plateau portion of the State, and seven more in the Basin and Range-Transition Zone portion. These are summarized as follows:

Colorado Plateau:

1. Pennsylvanian-Permian Naco and Supai Formations
2. Permian Kaibab Limestone
** 3. Jurassic Morrison Fm., Salt Wash Member
** 4. Triassic Chinle Fm.
5. Triassic Moenkopi Fm., basal portion
* 6. Jurassic Kayenta Fm.
* 7. Jurassic Navajo Ss.
* 8. Cretaceous Toreva Fm., of the Mesaverde Group
9. Cretaceous Dakota Fm.
** 10. Plateau breccia pipes
* 11. Pliocene Hopi Buttes, fine-grained clastics and tuffs

Southern Arizona:

** 12. Precambrian Dripping Spring Quartzite
* 13. Cretaceous sandstone
* 14. Oligocene, Miocene, Pliocene, fine-grained clastics
15. Mid-Tertiary volcanic rocks
* 16. Jurassic-Cretaceous volcanics, southernmost Arizona
** 17. Laramide porphyry copper deposits
* 18. Vein/pegmatite/granite occurrences, usually involving Precambrian crystalline terrain

**past or current major source in Arizona
*past or current minor source in Arizona

INTRODUCTION

Purpose and Scope

This report describes all known naturally anomalous radioactive occurrences in Arizona. Any locality where uranium mineralization was reported or radioactivity is two times or greater than background is considered anomalous. The major emphasis is placed on descriptions of geology, location, mineralogy, and radioactivity; less emphasis is placed on the history and detailed development of these occurrences.

Many uranium occurrences are concentrated in groups or districts, indicating a possible common genesis within the district. The first part of the report discusses sequentially each of these occurrence types, touching upon aspects of the relevant geology, and gives one or more examples of past uranium sources considered diagnostic of each type of occurrence.

The second part of the report lists in an abbreviated format the details of what is known about each of the 965 radioactive occurrences in the State.

All known data on pre-1971 uranium production is summarized and included. Post-1970 production data is not publicly available, but nevertheless is insignificant as compared to the pounds of U_3O_8 produced from Arizona before 1971. All production data to January 1, 1971, was compiled from official ore receipts (except for Monument Valley area) and supplemented by other Department of Energy (DOE) data.

Radioactive occurrences are listed alphabetically, county by county, and alphabetically within each county. The locations of occurrences, if known to within a section, are plotted on NTMS (1^ox 2^o) quadrangle maps. Four district maps for the Carrizo Mountains, Lukachukai Mountains, Cameron Area and Sierra Ancha Mountains, show the location of occurrences too numerous and concentrated to be plotted on the NTMS maps. Poorly located occurrences are not plotted but general description directions to these localities are provided.

The authors and/or the Arizona Bureau of Geology will appreciate receiving any additions or corrections to the data presented herein. Any information acquired after the publication of this report will be on file along with the data and reports from which this report is derived, at the Geological Survey Branch, Arizona Bureau of Geology, and available for public inspection. These files include details of past production and geology not found in this report.

Previous Work and Sources of Information

Most uranium mineral occurrences were prospected in the late 1940s and 1950s. During this time the Raw Materials Division of the U.S. Atomic Energy Commission identified many of the occurrences and monitored production from the active mines. Reconnaissance work by the A.E.C. and USGS geologists was documented in their brief preliminary reconnaissance reports (PRR). AEC and USGS geologists and others also compiled more detailed data on selected Arizona uranium occurrences and districts. These reports include those with

the following prefixes: TM's, RME's, RMO's, TEI's, and TEM's listed with the references.

More recent information is being accumulated by the U.S. Department of Energy (DOE) National Uranium Resource Evaluation (NURE) program. These reports (GJBX prefix) on aerial gamma ray and magnetic reconnaissance, hydrogeochemical and stream sediment analyses, special study areas and NTMS quadrangle evaluations are becoming available to the public as they are open-filed. The DOE has also open-filed many of the old AEC reports and preliminary maps of the Carrizo Mountains, Lukachukai Mountains and Cameron uranium mining districts. Published and unpublished open-file reports and declassified data files at the Grand Junction Office (Colorado) of DOE were examined for this report. See Table 1 for new NURE Arizona reports.

In 1970, Stanton Keith reported on 408 Arizona uranium occurrences in Arizona Bureau of Mines Bulletin 182 by Peirce and others. The Arizona Bureau of Geology and Mineral Technology (formerly Arizona Bureau of Mines) in cooperation with DOE has undertaken this new evaluation of uranium occurrences because significant additional information is now publicly available from formerly classified data and through the NURE Program. Arizona uranium occurrences are also summarized in Arizona Bureau of Geology Reports by Peirce and others (1977), and Scarborough and Wilt (1979) a commercial report by Waechter (1979), plus USGS open-file report on the Hopi Buttes Uranium Occurrences, scheduled for publication in 1981.

For this report, we depended heavily on the PRR's, open-file reports and maps, DOE data files, pre-1971 production records, and Arizona Bureau of Geology data files. Information was also obtained from individual mining companies, and both USGS and NURE geologists. Reconnaissance field trips to the Sierra Ancha Mountains, Lukachukai Mountains, Carrizo Mountains, Fredonia region, Cameron area, Grand Canyon, Date Creek Basin, New River area, San Pedro Valley, Whetstone Mountains, Santa Catalina Mountains, Safford area, Ruby-Arivaca area and Santa Rita Mountains helped to up-date information on many occurrences.

Acknowledgments

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Jenny Laber and Kenneth Matesich drafted the many figures for the report under the watchful eye of Mr. Joe LaVoie. Elizabeth Learned, DOE Grand Junction, compiled production histogram data and other related material. Review was provided by Bill Chenoweth, H. Wesley Peirce, and Anne Candea. Bob O'Haire kindly provided some identifications on puzzling mineral species.

Key to Individual County Listings

Descriptions of all radioactive mineral occurrences in Arizona are listed alphabetically by geographic location and by county. A state-wide alphabetical listing is provided in the index. Aliases for the occurrence names are included in both county descriptions and index.

The descriptions of occurrences in this report are brief summaries of available pertinent data. Obviously, not all data could be included. For some occurrences the information is very limited or held confidential by companies. See also page 103 for instructions on use of the individual listings.

The descriptions contain the following information:

1) Name

Name of occurrence, associated claims, and aliases. A name in parenthesis indicates that is the name under which the information for that property is listed.

2) Location

Location as Section, Township and Range or as latitude and longitude for unsurveyed areas. If there was any question concerning the location of an occurrence within the section or if the occurrence location was defined by U.S. Bureau of Land Management protracted Township and Range, the word approximate (Approx.) precedes the given location. Geographic location, i.e. mountain range, is also provided. Descriptive directions are taken from the PRR's for poorly located occurrences. Locations were field checked when possible. PRR locations were not always correct. Every effort was made to provide accurate locations to within a section. The NTMS and district maps show the distribution of most occurrences. Poorly located occurrences are not plotted.

3) Quadrangle

The names of the appropriate 7½' and/or 15' USGS topographic and 1^{o} X 2^{o} (NTMS) maps are provided.

4) Development

A short description of the type and extent of prospecting and mining at the site.

5) Production

Tons and grade of ore are from official ore receipts. Tons are calculated on moisture-free basis, and uranium-vanadium contents are based on assays before mill processing.

6) Radioactivity

The maximum radioactivity at the site is expressed as times background. All sites with radioactivity 2X or greater than background are listed.

7) Analyses

The sample analyses represent a summary of the radiometric and chemical assays provided in the various reports. When radiometric and chemical assays are given for the same sample, they are listed together on the same line, with the letter "e" preceding the U_3O_8, indicating that the value was determined radiometrically. No "e" indicates a chemical assay. Disequilibrium between uranium and its radioactive daughter products is indicated by a discrepancy between radiometric and chemical assays.

8) Geology

This is a brief summary of the host rock, mineralogy, stratigraphy, alteration, and structure. Not all information could be provided for some occurrences.

9) References

A short citation format is used for the sources of information in the individual listings. Full reference citations are provided in the listing of references. Two numbers may accompany referenced PRR's. The first is the file number recorded on the PRR when it was made. The second, in parenthesis, is a hand-posted number used by the Bendix library at Grand Junction, sequenced county by county.

10) Mine Maps and Geologic Cross Section

Mine maps and geologic cross sections are provided for some occurrences and are located in the general discussion sections occupying the first part of the report.

Table 1

NURE REPORTS COVERING ARIZONA

2° Quad	HSSR*	Early Air	Air*	Other*
Shiprock	143(80)		116(79)	
Marble Canyon	--		16(80)	
Grand Canyon	142(80)		35(80)	
Las Vegas	123(78)		59(79)	
Gallup	186(80)		116(79)	
Flagstaff	--		157(79)	
Williams	71(79)		59(79)	
Kingman	122(78)		59(79)	44(76)[1]
St. Johns	191(80)		126(79)	69(78)[2]
Holbrook	--		--	--
Prescott	122(79)		59(79)	72(79)[3]
Needles	--		114(79)	86(80)[4] 164(80)[5]
Clifton	69(78)	GJO-1643	23(79)	
Mesa	81(80)	GJO-1643	23(79)	
Phoenix	--		12(80)	
Salton Sea	113(80)		12(80)	
Silver City	69(78)	GJO-1643	23(79)	
Tucson	--	GJO-1643	23(79)	
Ajo	--		12(80)	
El Centro	--		12(80)	
Douglas	69(78)	GJO-1643	23(79)	
Nogales	--	GJO-1643	23(79)	102(79)[6]
Lukeville	--		12(80)	102(79)[6]

*GJBX prefix

[1]HSSR Roach Lake (in Nevada)

[2]HSSR portions of Douglas, Silver City, St. Johns, Clifton

[3]Artillery Peak HSSR; 164(80)

[4]Date Creek Drilling

[5]HSSR Date Creek Basin

[6]Papago Indian Reservation HSSR

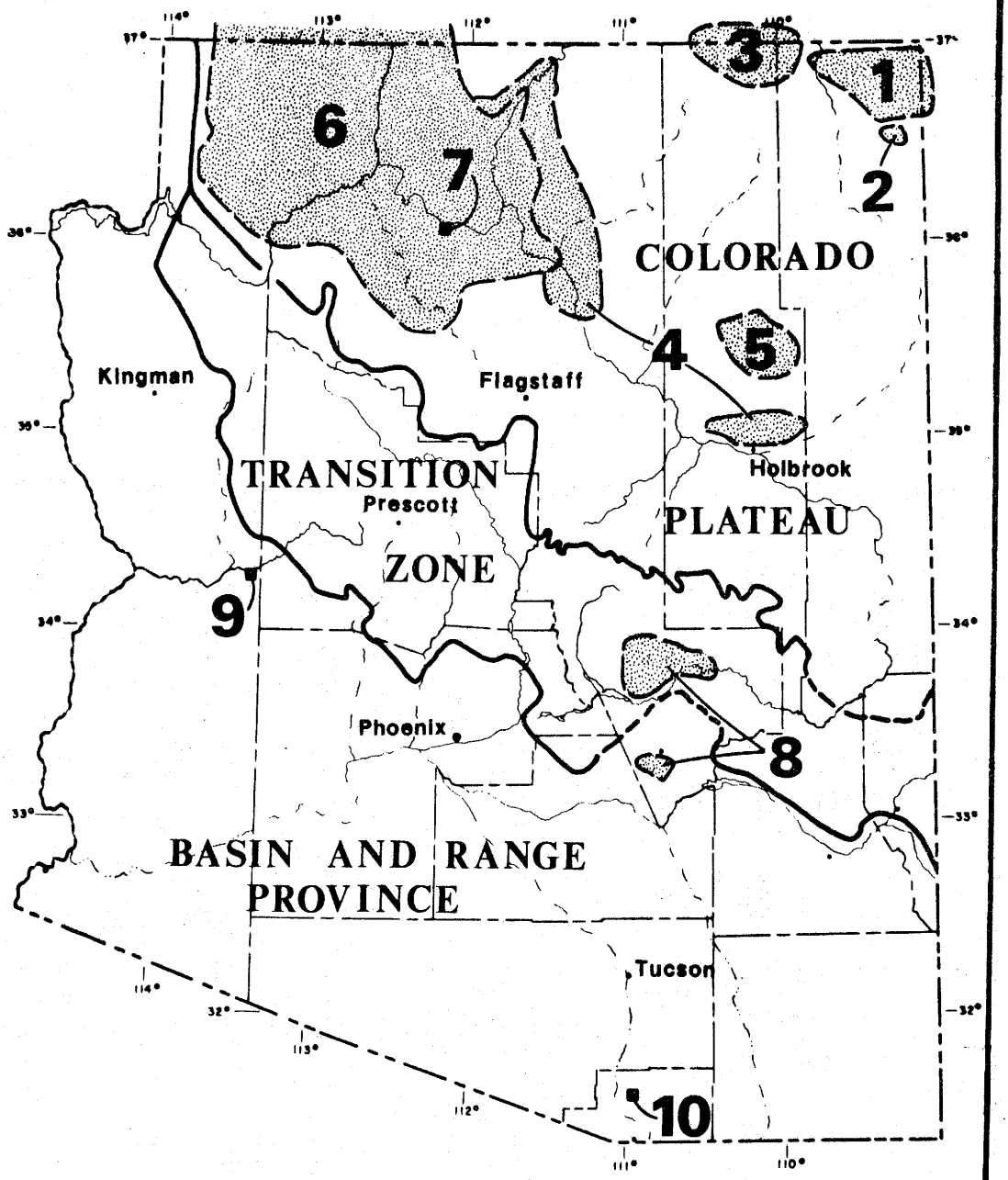
URANIUM OCCURRENCES IN ARIZONA

The first part of this report presents general discussions of the major uranium producing districts and environments in Arizona. For the sake of organization, the discussions are divided into two sequences, the Colorado Plateau, and Southern Arizona (in that order), based upon the physiographic division of the State adopted in Figure 1. Southern Arizona here is taken to be the totality of the Basin and Range Province and the Transition Zone Province. This two-part breakdown of uranium occurrences in the State follows logically from the very different geology and types of uranium host rocks found in the two regions. The Colorado Plateau occurrences are divided between Mesozoic-aged stratabound deposits and breccia pipe deposits. Southern Arizona occurrences also consist of some stratabound deposits in Cenozoic, Cretaceous, and Precambrian sedimentary host rocks, but in addition include vein-type and crystalline host rock types. Figure 1 also illustrates the districts with significant past uranium production. Notes concerning thorium occurrences in Arizona are given after the uranium discussions.

The Colorado Plateau portion of Arizona consists of a relatively complete and continuous flat-lying sequence of Paleozoic and Mesozoic cratonic sediments, rather gently deformed by a series of folds and monoclines. In contrast, the Basin and Range portion of the State consists of an extremely fragmented, faulted record of Proterozoic basement rocks overlain by locally preserved Paleozoic, Mesozoic, and Cenozoic sedimentary and volcanic rocks. This sequence is chopped up along a series of late Cenozoic-aged, quasi-parallel NW-SE trending faults which have in effect created discontinuous elongate mountain ranges and adjacent broad wide valleys that represent horst and graben blocks. Intense orogenies during Mesozoic and Cenozoic times, culminating with the Basin and Range disturbance described above, have served to fragment Basin and Range geology into a very incompletely understood record.

The physiographic province called the Transition Zone is a long narrow region that displays certain structural and stratigraphic properties of each of the two adjacent provinces.

Figure 1A illustrates a simplified State-wide stratigraphic correlation chart. It includes approximate stratigraphic positions for the most prominent uranium deposits and occurrences in the State.



Colorado Plateau Province

1. Carrizo Mountains
2. Lukachukai Mountains
3. Monument Valley
4. Cameron region
5. Hopi Buttes volcanic field
6. Plateau breccia pipes
7. Orphan Lode

Southern Arizona

8. Dripping Spring Quartzite
9. Anderson Mine
10. Duranium Mine

PHYSIOGRAPHIC PROVINCES AND MAJOR URANIUM DISTRICTS IN ARIZONA

Figure 1

[The stratigraphic nomenclature and age designations used in this chart do not necessarily follow the usage of the U.S. Geological Survey, but follow the usage of authors who have described the several parts of the State. Terms in italics refer to informal rock stratigraphic units. Rock units known only in subsurface marked by asterisk (*). Arrows indicate known or possible wide range in age of named unit or that unit may be younger or older than indicated by position on chart.]

Geologic time units			Southeast (Includes Mexican Highland section)	Southwest (Includes Sonoran Desert section)	Central (Includes Tonto and Flagstaff sections)	Northwest (Includes Grand Canyon and Mohave sections)	Northeast (Includes Navajo section)
Cenozoic	Quaternary		*Alluvial deposits, basalt*	*Alluvial deposits, basalt*	*Alluvial deposits, basalt* *	*Alluvial deposits, basalt* *	*Alluvial deposits, basalt*
	Tertiary	Pliocene	Gila Conglomerate *	*Basin fill deposits*	Verde Formation Gila Group * / Hickey Formation	Muddy Creek Formation *	Bidahochi Formation *
		Miocene	*Volcanics*	*Volcanics* *	*Volcanics* * *	*Local volcanics and sediments* *	Chuska Sandstone
		Oligocene	Whitetail Cgl. --Pantano Fm. *	Helmet Fgl. --Locomotive Fgl.			
		Eocene					
		Paleocene					
Mesozoic			*Andesites and rhyolite*	*Andesites and rhyolite*	*Andesites*	*Andesites* *	
	Cretaceous		*Local sedimentary formations* * / Pinkard Formation (north) / Bisbee Group (south) / *Local volcanics (south)* *	*Locally named sedimentary, volcanic, and metamorphic rocks of poorly understood or unknown age relations*	*Local sedimentary rocks*		Mesaverde Group * / Mancos Shale / Dakota Sandstone
	Jurassic		*Local volcanics* *			breccia pipes * / Carmel Formation	Morrison Fm. / Bluff Sandstone / Summerville Fm. / Todilto Limestone / Entrada Sandstone / Carmel Formation — Cow Springs Ss.
						Navajo Sandstone	Navajo Sandstone *
	Triassic		*Local red beds* / *Local volcanics*			Kayenta Formation / Moenave Formation / Chinle Formation * / Moenkopi Formation	Kayenta Formation * / Wingate Sandstone / Chinle Formation * / Moenkopi Formation
Paleozoic	Permian		Rainvalley Formation / Concha Limestone / Scherrer Formation / Epitaph Dolomite / Colina Limestone / Earp Formation	Concha Limestone / Scherrer Formation / Epitaph Dolomite / Colina Limestone / Earp Formation	Kaibab Limestone / Coconino Sandstone / Supai Formation *	Kaibab Limestone * / Toroweap Formation / Coconino Sandstone / Hermit Shale / Supai Formation	De Chelly Ss. / Supai Fm. — Cutler Fm. / Rico Fm.* / Hermosa Fm.* / Molas Fm.*
	Carboniferous	Pennsylvanian	Horquilla Limestone / Black Prince Limestone (local)	Horquilla Limestone	*Naco Formation*	Callville Limestone	
		Mississippian	Paradise Formation (east) / Escabrosa Limestone	Escabrosa Limestone	Escabrosa Ls. or Redwall Ls.	Redwall Limestone	Redwall Ls.*
	Devonian		Martin Formation	Martin Formation	Martin Formation	Temple Butte Limestone or Martin Formation	Ouray Ls.* / Elbert Fm.*
	Silurian						
	Ordovician		El Paso Limestone (east)			*Unnamed dolomite*	
	Cambrian		Abrigo Formation / Bolsa Quartzite	Abrigo Formation / Bolsa Quartzite	*Tapeats Sandstone*	Muav Limestone / Bright Angel Shale / Tapeats Sandstone	Tapeats(?) Ss.*
Precambrian	Late Precambrian		Troy Quartzite / Apache Group *	Apache Group	Troy Quartzite * / Apache Group: *Basalt*, Mescal Limestone, Dripping Spring Qtzt., Pioneer Shale	Chuar Group / Unkar Group: Nankoweap Formation, Rama Formation, Dox Sandstone, Shinumo Quartzite, Hakatai Shale, Bass Limestone, Hotauta Cgl.	
	Early Precambrian		Pinal Schist *	*Metamorphic rocks*	Mazatzal Quartzite * / Yavapai Series: Alder Group, Ash Creek Group	* / Brahma Schist / Vishnu Schist	*Metamorphic rocks*

from Arizona Bureau of Mines Bulletin 180, (1969), p. 40-41.

* major producers for a region

* major occurrences, some with minor production

Figure 1A. Simplified stratigraphic correlation chart for Arizona. Included are approximate stratigraphic positions of important uranium deposits and occurrences.

COLORADO PLATEAU REGION

MORRISON FORMATION

In the Four Corners area the Morrison Formation of Upper Jurassic age is a regionally dominant source of uranium, with production from Utah, Colorado, and New Mexico far outweighing that of northeastern Arizona. The lowest member, the Salt Wash, is the sole source of Morrison ore in Arizona, while stratigraphically higher members, the Recapture, Westwater Canyon, and Brushy Basin, contain ores in the adjacent states. As well, these upper members contain volcanogenic beds which are hypothesized by some as uranium source beds.

For descriptions of Morrison Formation geology, see Mullens and Freeman (1957), Chenoweth and Malan (1975), and Galloway (1979). For uranium-related geology, refer to Masters (1955), Chenoweth (1955 and 1967), Stokes (1954), Wright (1955), and Dare (1961). For district maps, see DOE (ERDA) Preliminary Map No. 23.

Salt Wash Member ores in Apache County, Arizona supplied 815,100 tons of ore which contained 0.236% U_3O_8 (3,850,000 lbs) and 1.098% V_2O_5 (17,900,000 lbs) between 1948 and 1968. In addition, minor uranium was recovered from mill tailings from early Carrizo vanadium mine workings operated during 1942-1944. Total production from Salt Wash ores may be divided between the Lukachukai Mountains (724,800 tons of ore @ 0.24% U_3O_8 and 1.02% V_2O_5 in 1950-1968 from 53 properties) and the Carrizo Mountains to the north (90,300 tons of ore @ 0.20% U_3O_8 and 1.75% V_2O_5 in 1948-1966 from 71 properties.)

Radioactive ores in the Salt Wash Member of the eastern Carrizos were first mined in about 1920 and sent to Colorado for extraction of radium content. During 1942-1944 Salt Wash ores were mined in the Carrizos by the Vanadium Corporation of America and Wade, Curran and Company for vanadium and mining for uranium in these same deposits began in 1948. Mining continued in the Carrizos and Lukachukais until 1968. See Dare (1966) and Chenoweth (1980 a and b) for historical development of mining in the Carrizos and Lukachukais.

Studies of the Salt Wash Member by Craig and others (1951), Mullens and Freeman (1957), Masters (1955), and Peterson (1977) in Utah, Colorado, Arizona, and New Mexico indicate that these sediments were deposited by a proximal aggrading braided stream system on a massive alluvial fan and a more distal delta distributary system, the upstream apex of which was near what is today Lee's Ferry on the Colorado River. See Figure 2 for the fan geometry. Distributary channels in eastern Utah flowed generally northeasterly, while those in northeast Arizona and northwest New Mexico flowed easterly. In detail, the Salt Wash Member of northeast Arizona and northwest New Mexico is considered a separate eastern lobe of the main Salt Wash fan system of Utah and Colorado. The Lukachukais are near the thickest part of this lobe (Mullens and Freeman, 1957, Figure 4). Similarly, the Grants mineral belt is on the most southerly lobe of the Westwater Canyon fan system whose apex is somewhat south of Window Rock, Arizona (Galloway, 1979, Figure 2).

In northeast Arizona the Salt Wash beds, resting on a scoured surface cut on predominantly eolian Jurassic Bluff Sandstone (Figure 3), range in thickness

from 100-180 feet. They are overlain by about 400 feet of Recapture Member fluviatile beds. All Mesozoic units in northeast Arizona as young as Cretaceous Dakota Sandstone are involved in folding (see the district maps of this report) and are beveled and overlain by the non-folded Eocene (?) Chuska Sandstone of the Chuska and Lukachukai Mountains. The Salt Wash Member in Northeast Arizona consists mainly of lenticular, gently cross-bedded sandstones, with minor pebbly sandstones, mudstones and claystones as discontinuous partings between the sandstone beds. The units weather to resistant ledges and cliffs, and cap broad benches and mesas. Most beds are between 6 and 30 feet thick. Fossil logs are common, and fragmental carbonized plant debris forms seams along bedding planes, and finer fragmental material is disseminated through the sandstones.

Only sparce uranium-vanadium occurrences are known in northeastern Arizona in units directly above or below Salt Wash outcrops. In the Lukachukai Mountains, several sub-ore grade uranium occurrences are known from the overlying Recapture Member fluvial beds (Chenoweth, 1967, p. 82). And in the underlying Bluff Sandstone, Chenoweth and Fergusson (PRR ED:R-263, 1954) describe an interesting vanadium occurrence which lacks appreciable uranium. In a reentrant near the crest of the Rattlesnake anticline, a short distance east of the Sweetwater T.P. road, vanadium staining is found 10 feet above the base of the Bluff Ss in a horizonal showing, with darkest coloration following individual cross-bed laminations. Uranium assays are negative. Clearly, vanadium has migrated without attendant uranium.

Lukachukai Mountains

In the Lukachukai Mountains, uranium ore is most common in trough cross-stratified sandstone that fills scours and channels in under-lying mudstones. The ore bodies are elongate and lenticular, consisting of one or more pods surrounded and separated by protore. Ore trends parallel paleostream directions, but often trend along a locally prominent joint set, suggesting some remobilization of uranium minerals (Stokes 1954; Nestler and Chenoweth, 1958; Chenoweth, 1967; Chenoweth and Malan, 1975).

Ore bodies occur some 30-80 feet above the base of the Salt Wash Member. All of the significant deposits (99.6% of total Lukachukai production) are located in a well-defined belt which trends nearly north-south across the southeast end of the mountains (Chenoweth and Malan, 1975). They lie on the shallow-dipping southwest limb of the Chuska syncline and are confined to a favorable interbedded sandstone-mudstone facies of the Salt Wash (see enclosed Lukachukai district map).

Tyuyamunite, the most common uranium-vanadium mineral, is irregularly disseminated through sandstone beds, and is concentrated in lenses, or distributed in bands. It fills sandstone voids, coats sand grains, and replaces calcite and carbon. Some uraninite replaces carbonaceous matter and fills sandstone voids in some incompletely oxidized ore bodies. Hence, a question arises as to the nature of the originally precipitated uranium species. Are the tyuyamunite deposits to be viewed as alteration products of pre-existing uraninite deposits? Calcite is found as a cement in the sandstone ore bodies, and probably moved in with the uranium (Chenoweth and Malan, 1975). Limonite staining, halos, and bands are common in ore-grade material.

Figures 4, 5 and 6 show outline maps of the Lukachukai Mesas I - VI mines. Figures 7 and 8 portray outline maps of the Frank No. 1 and Camp mines, respectively, which are typical of Lukachukai mines.

Carrizo Mountains

The general aspect of the Carrizo Mountains uranium deposits is very similar to the Lukachukai deposits, with some notable variations. The ore horizons in the Salt Wash tend to be in lower parts of the unit toward the northwest from the Lukachukais, such that in the northwest Carrizos they are in the basal 40 feet of the unit (Chenoweth and Malan, 1975, table 2). The ore bodies tend to be smaller than in the Lukachukais, and they have vanadium-uranium ratios near 9:1, as compared with 4:1 ratios in the Lukachukais. Also, ore rolls are more common in the Carrizos.

The main mass of the Carrizos consists of a series of Laramide-aged laccoliths (68 m.y. on one unit, Armstrong, 1969) which have intruded rocks as young as the Dakota Sandstone. No obvious large-scale redistribution of Carrizo Salt Wash uranium ores are known to have taken place as a result of this heating event. And at the Zona mine in the northeastern Carrizos, intrusion of the sills fractured, faulted, and silicified typical Salt Wash ore horizons, providing the only evidence in Arizona that the uranium mineralization event is pre-Laramide in age (Chenoweth and Malan, 1975, p. 147).

Figures 9-15 are in the Carrizo Mountains area. Figures 9 and 10 depict the Tsitah (Saytah) Wash area with the Martin, Saytah, and George Simpson mines. Figures 11 and 12 show mines of the Rattlesnake group and the Hoskie Henry mine of the northwest Carrizos. Figures 13 and 14 show the Oak Springs and RF&R-Hazell-Valley View mines of the eastern Carrizos. Figures 15a and 15b cover the productive Cove Mesa area of the southern Carrizos.

Black Mesa

Salt Wash sediments are well exposed on the northeast flank of Black Mesa. Fourteen miles north of the Black Mountain uranium mines in the Toreva Formation, two properties located north of the Rough Rock Trading Post in the Salt Wash Member (Tom Wilson and Tom Klee, Apache County) shipped 123 tons of ore averaging 0.75% U_3O_8 and 0.03% V_2O_5 between 1951 and 1958 (DOE (AEC) Map No. 31, 1973). The Salt Wash Member here consists of about 130 feet of interbedded fine-grained gray to gray-brown sandstone and gray, green and reddish-brown siltstone and mudstone. Secondary uranium minerals are associated with carbonaceous fossil logs and other disseminated carbonized plant debris, in sandstone lenses 10 to 40 feet above the base of the Salt Wash Member (DOE Map No. 31 data). Abundant calcite crystals associated with the logs produced an average of 31% $CaCO_3$ in the ore shipments.

Morrison Mineralization - Timing and Source

The prevailing opinion on the time of uranium mineralization in the Morrison Formation in Arizona is that it was shortly after deposition of Salt Wash beds, perhaps still in Morrison time (F. Peterson, pers. comm., 1980) or perhaps during Cretaceous or Early Tertiary weathering and erosion marked by a pre-Dakota Sandstone or pre-Chuska Sandstone erosional unconformity (W. Chenoweth, pers. comm., 1980), but, at any rate, was pre-Laramide in age. Uranium series age dating of uranium ores in the Grants mineral belt by Brookins (GJBX 16-76 and 141-79 reports issued by DOE) indicate ages of mineralization of about 138 $\pm$ 10 m.y. at Ambrosia Lake, and 110-115 m.y. in the Jackpile-Paguate area. Authigenic montmorillonite from both these areas was dated at 145 $\pm$ 10 m.y. (last half of upper Jurassic), and may represent either the time of initial diagenesis of Morrison beds or time of ore deposition at Grants.

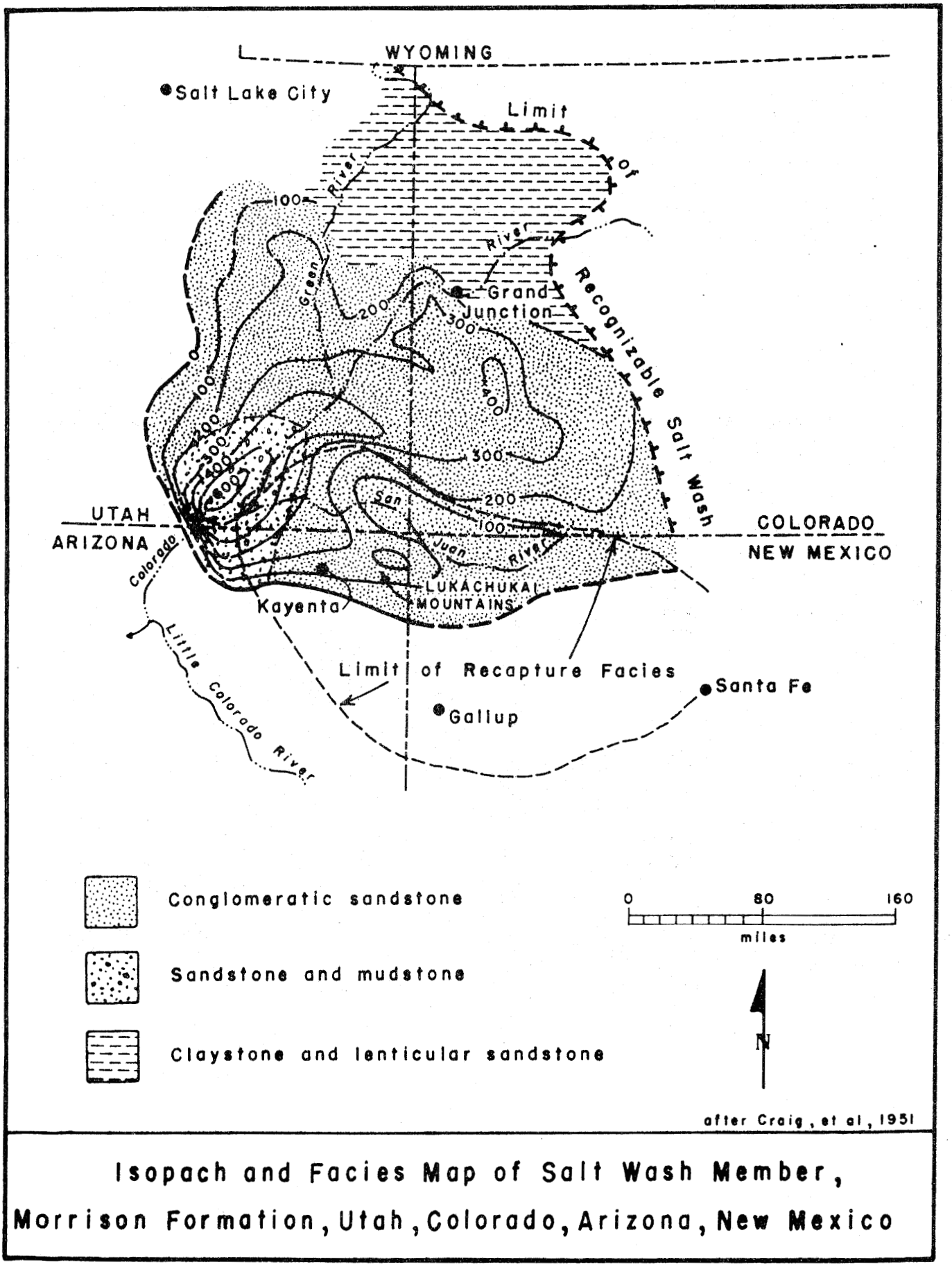
Uranium in the Salt Wash could have been derived from sources such as volcanic detritus in the overlying Brushy Basin Member during the pre-Chuska erosion in the area (Nestler and Chenoweth, 1958, p. 53). However, a more regional picture, assembled with the help of plate tectonic theory, indicates the existence of a volcanic arc starting in late Permian time along the west coast of North and South America, temporally related to the formation of the modern Atlantic Ocean. This arc volcanism is the most probable source of volcanic debris and ash beds of the Mesozoic sediments of the Colorado Plateau, and is probably tied in with the tectonics which formed the "Mogollon highlands" of southwest Arizona and points west (Malan, 1968; Repenning and others 1969; Hamilton, 1978). Hence a model for Salt Wash mineralization is volcanogenic sources in the Mogollon highlands supplying uranium-vanadium-copper species for surface or underground aqueous transport downslope to areas of sedimentation where appropriate geochemical conditions caused precipitation. However, it is still not clear how the stratabound uranium-vanadium mineralization of the Salt Wash relates to mineralization of uranium-copper in the Plateau breccia pipes. Perhaps the pipes may be viewed as conduits or local sinks which trapped copper and some uranium while vanadium, most uranium, and many other elements continued to migrate eastward and northward onto today's Colorado Plateau where reduction and precipitation took place under appropriate conditions. The southern Utah uranium-copper association in some Shinarump paleochannels may be viewed as a hybrid case where ore-grade copper occurs in the sedimentary environment. Silver, et al. (1980) suggest the presence of a regional uranium anomaly in the Precambrian basement beneath the Colorado Plateau, based on uranium content of zircons extracted from igneous rocks. However, it is not clear how this basement anomaly may explain the numerous large-scale stratabound uranium deposits found at the top of the preserved Mesozoic units some distance above the basement.

Potential

Some potential remains for uranium in the Salt Wash Member in northeast Arizona. Ore deposits were located in the 1950's by exploiting mineralized outcrops, first by "gophering", and later by drilling behind the outcrops. Hence, all major mines are located very near cliffs exposing Salt Wash strata. Many of these cliffs are along stream valleys that dissect middle limbs of monoclines or steeper limbs of anticlines.

Future exploration must probably take one of two forms. First, reevaluation of the old mines could be undertaken by careful mine mapping and drilling, being careful to take note of the known ore trends in the area (see individual mine maps). Secondly, exploratory drilling on an arbitrary grid around old mines could prove successful. The Block K and George Simpson "1B" Mines of the northwest Carrizos and some of the Cove Mesa Mines (southern Carrizos), among others, were discovered in this fashion. The Block K Mine was discovered by a single AEC drillhole placed through valley fill which buries the north limb of the Toh Atin anticline. Since most of the Salt Wash mines of the northwest Carrizos were near the crest of this structure, and since the productive Rattlesnake Mine group (Figure 11) was north of the fold crest near the edge of onlap of valley fill, the AEC decided to test the Salt Wash to the north where it was buried. Block K resulted. The George Simpson "1B" Mine was discovered by a drilling program on the Mesa top due west of the old Martin Mine. That area was chosen because an east-west Salt Wash ore trend was thought to exist in the Martin. Mineralized Salt Wash was encountered in the

drilling and, during access tunneling driven from the Martin workings, an additional ore pod was discovered half way between the two areas. Similarly, George Simpson explored near the old Saytah Mine, just south of the Martin, and discovered additional ore nearby which was mined by the George Simpson "1A" and Incline Mines (Figure 10). Certainly, other situations similar to these still remain in the Carrizo and Lukachukai Mountains. The Salt Wash Member exposed around Black Mesa has been thoroughly explored with only three areas of mineralization noted, the Tom Wilson and Tom Klee shipments from north of Rough Rock Trading Post; the poorly located Blue Lake claim farther north; and one unrecorded occurrence somewhere around Kayenta (W. Chenoweth, pers.comm.,1981). The sparcity of Salt Wash mineralization in this southwest region may relate to a less favorable paleoenvironmental setting recorded as thinner individual sandstone beds and more dominant mudstone-siltstone lithologies as compared with the Carrizo-Lukachukai area. However, the mineralized logs in Salt Wash strata at Tom Wilson and Tom Klee indicate uranium moved through the strata, at least in the northeast Black Mesa region.



Isopach and Facies Map of Salt Wash Member, Morrison Formation, Utah, Colorado, Arizona, New Mexico

Figure 2

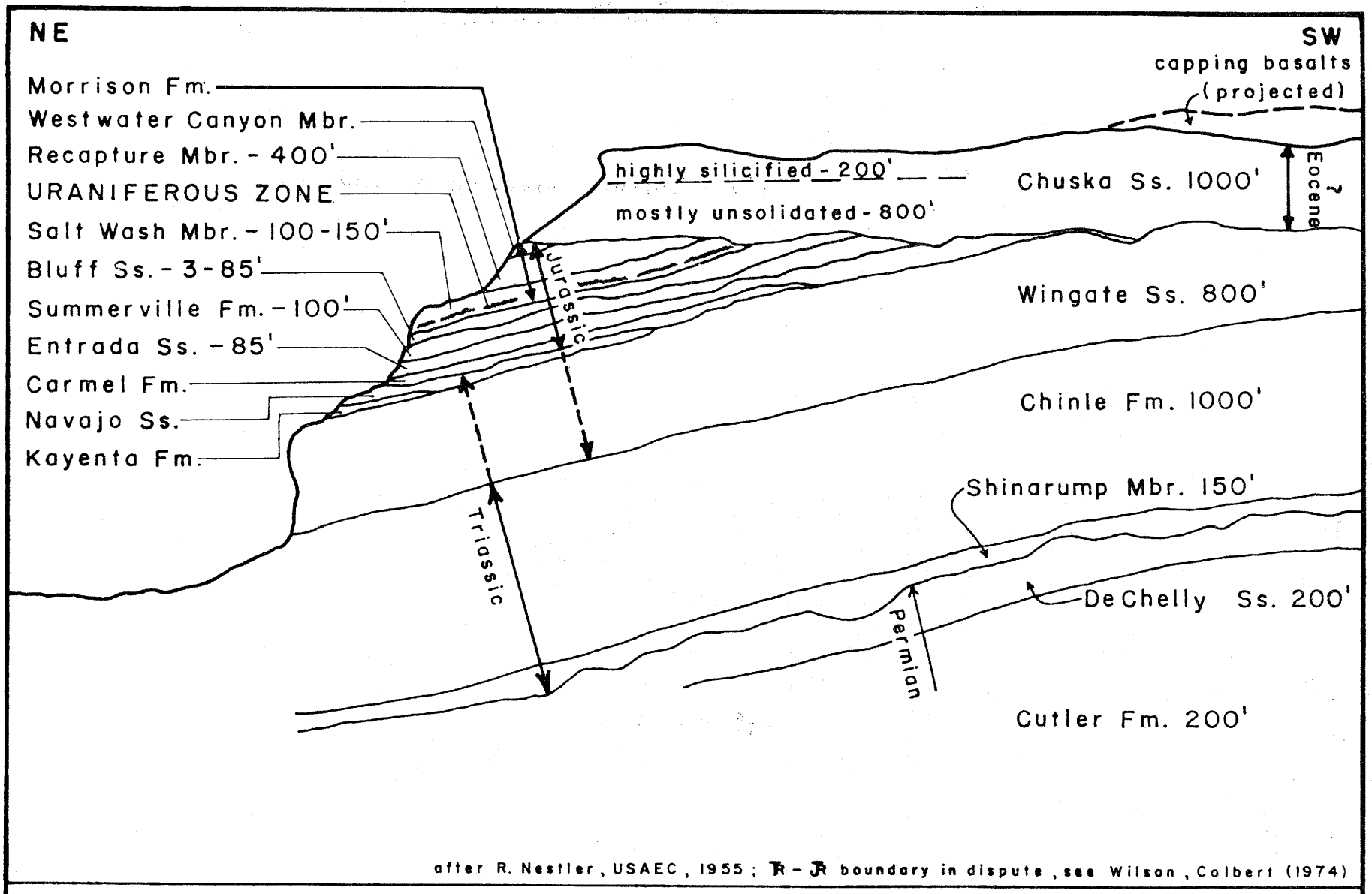
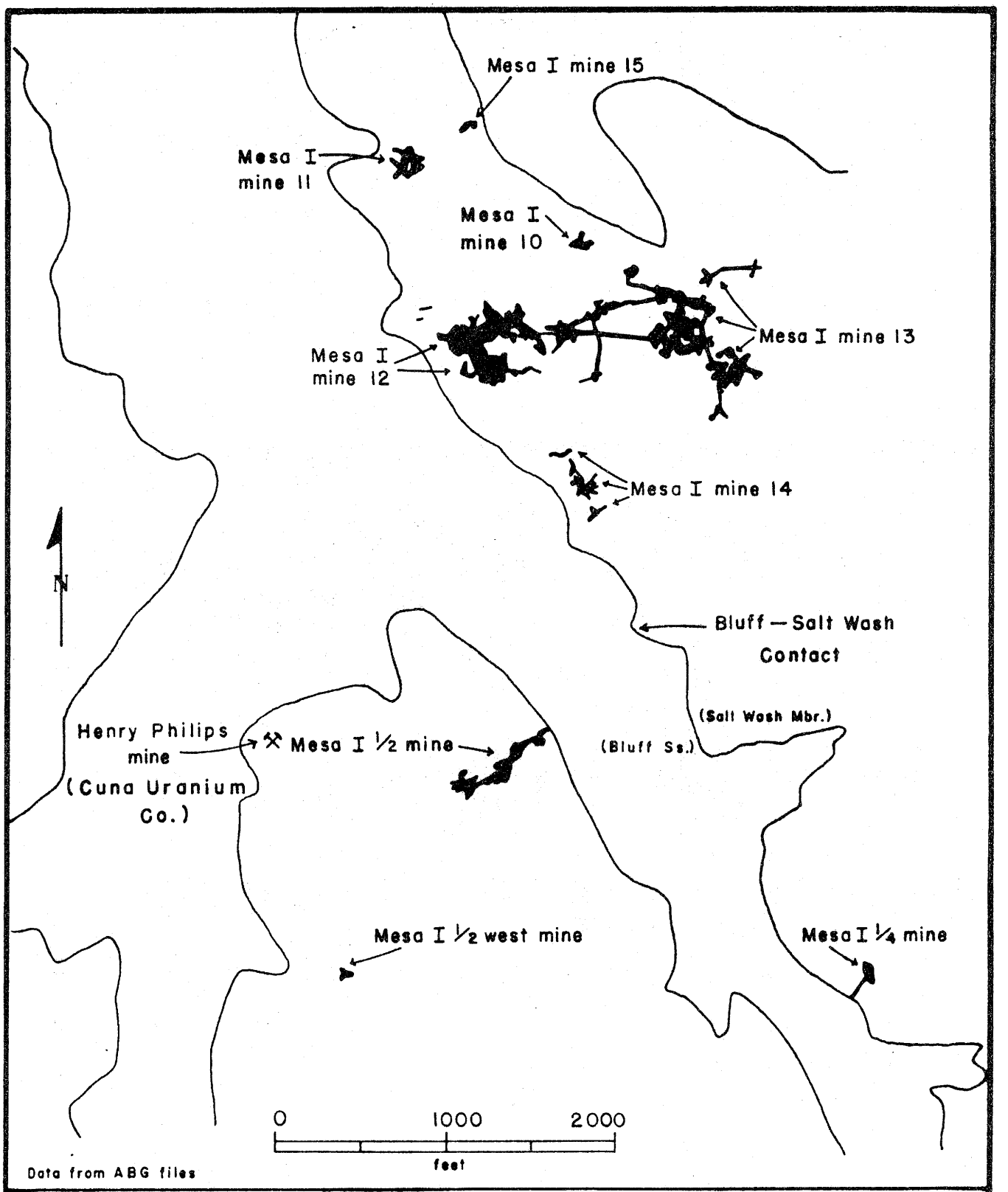


Figure 3

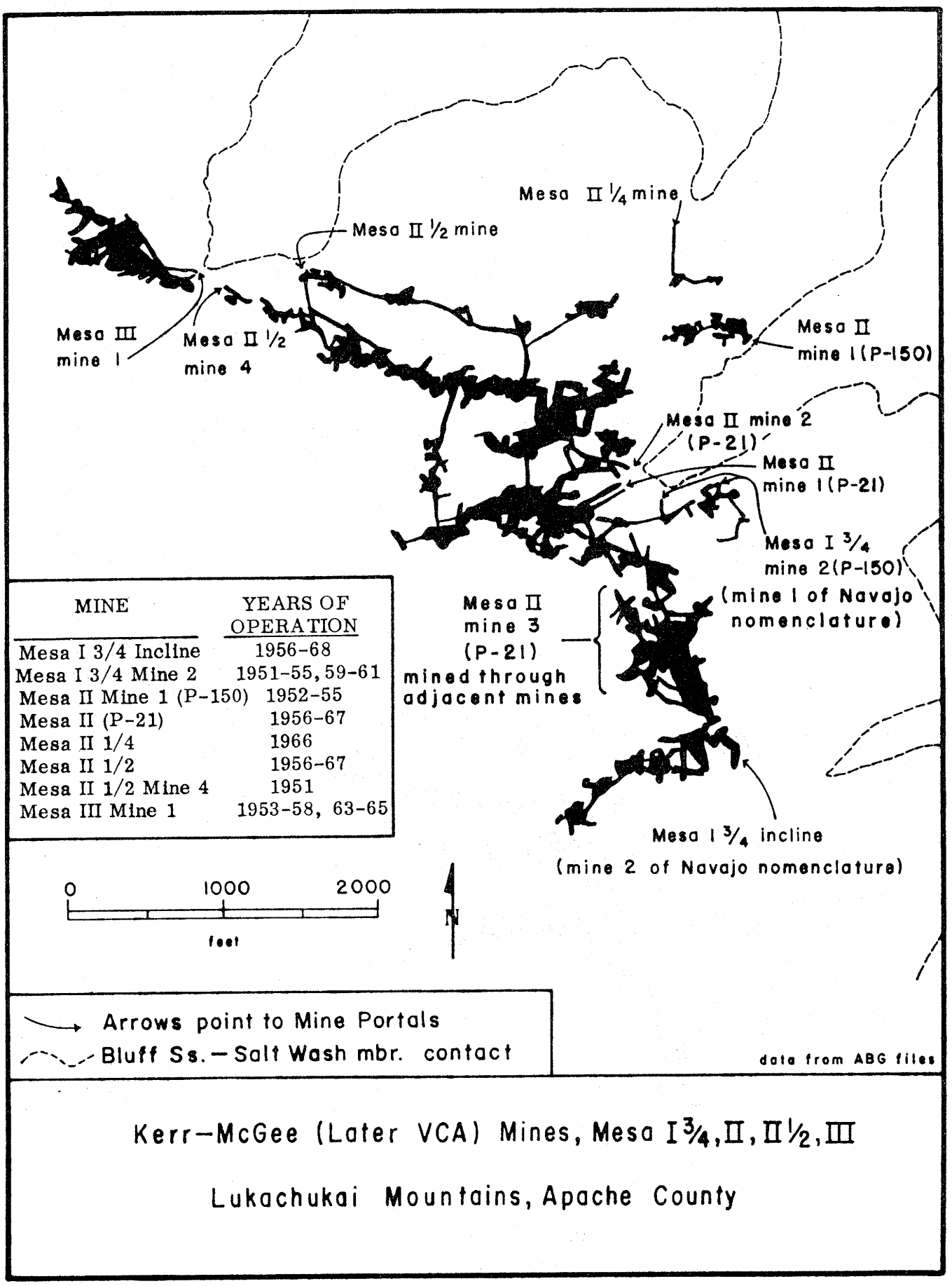
Generalized Geologic Cross Section across the Lukachukai Syncline, Lukachukai Mountains, Apache County



Kerr — McGee (Later VCA) Mesa I, I½, I¼ Mines

Lukachukai Mountains, Apache County

Figure 4

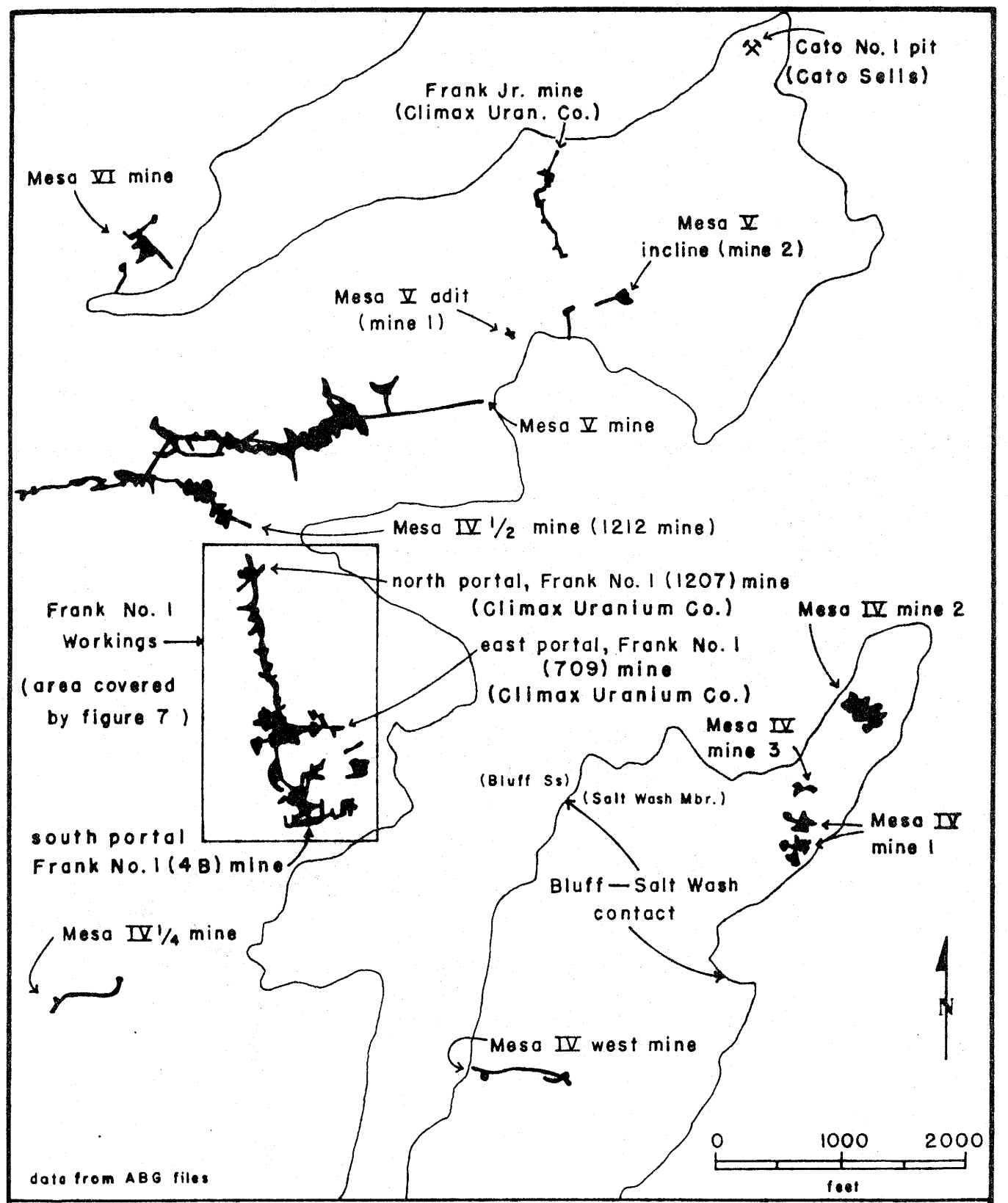


MINE	YEARS OF OPERATION
Mesa I 3/4 Incline	1956-68
Mesa I 3/4 Mine 2	1951-55, 59-61
Mesa II Mine 1 (P-150)	1952-55
Mesa II (P-21)	1956-67
Mesa II 1/4	1966
Mesa II 1/2	1956-67
Mesa II 1/2 Mine 4	1951
Mesa III Mine 1	1953-58, 63-65

Kerr–McGee (Later VCA) Mines, Mesa I¾, II, II½, III

Lukachukai Mountains, Apache County

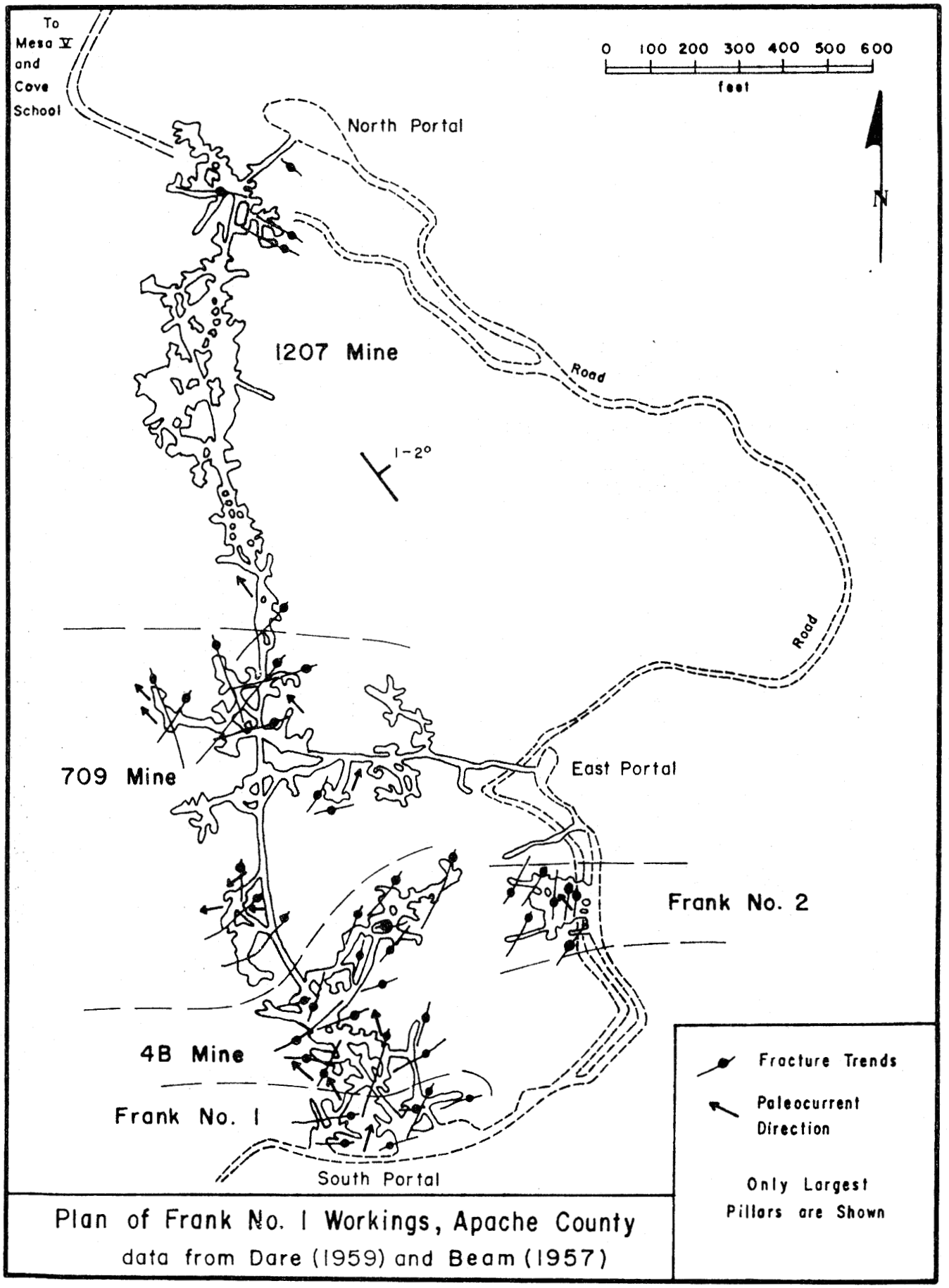
Figure 5



Kerr—McGee (Later VCA) Mesa IV, IV 1/4, IV 1/2, V and VI Mines

Lukachukai Mountains, Apache County

Figure 6



Plan of Frank No. 1 Workings, Apache County
data from Dare (1959) and Beam (1957)

Figure 7

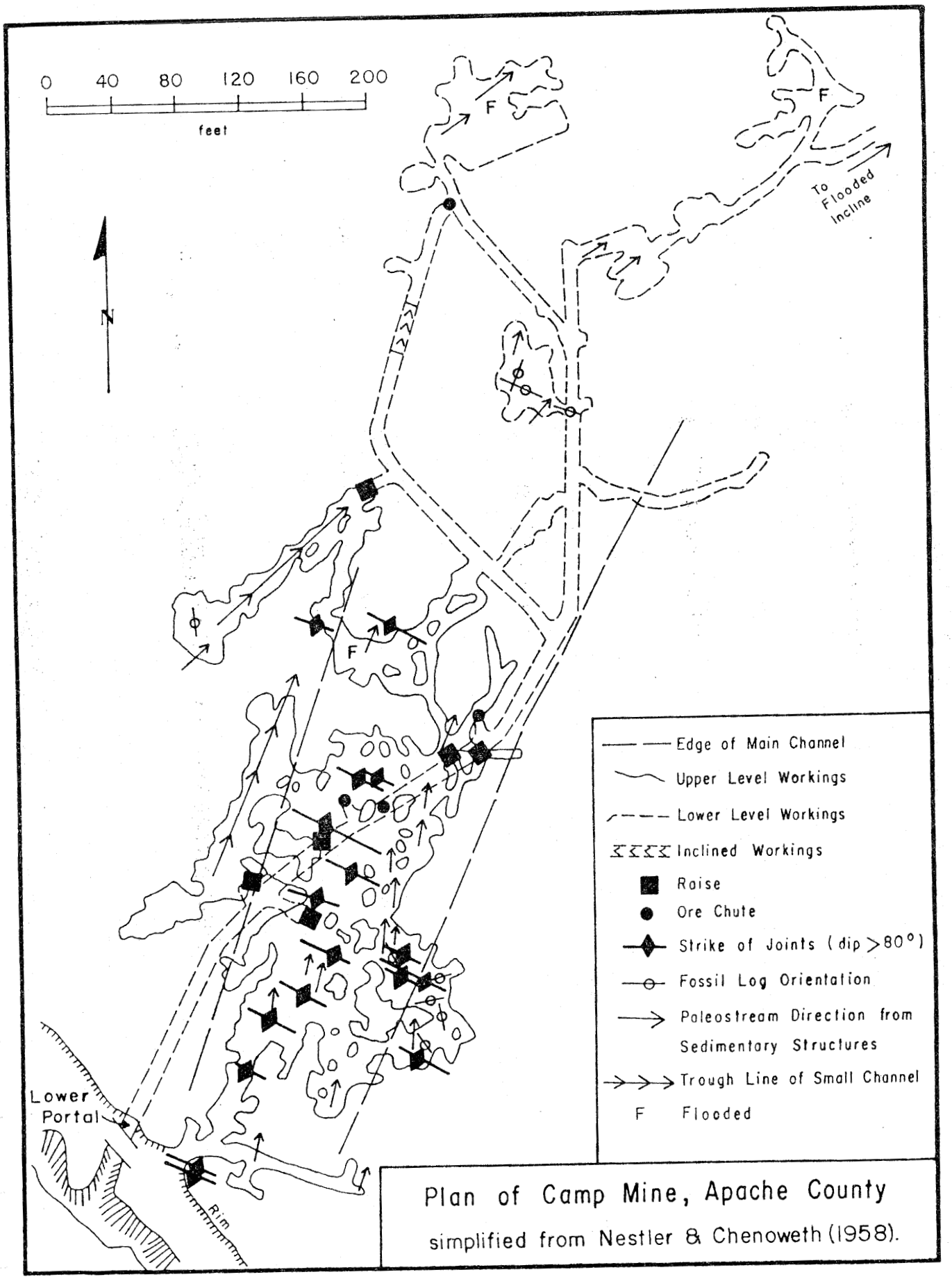

0 40 80 120 160 200
feet
N
F
F
To Flooded Incline
F
Lower Portal
Rim
Edge of Main Channel
Upper Level Workings
Lower Level Workings
Inclined Workings
Raise
Ore Chute
Strike of Joints (dip >80°)
Fossil Log Orientation
Paleostream Direction from Sedimentary Structures
Trough Line of Small Channel
F Flooded
Plan of Camp Mine, Apache County
simplified from Nestler & Chenoweth (1958).

Figure 8

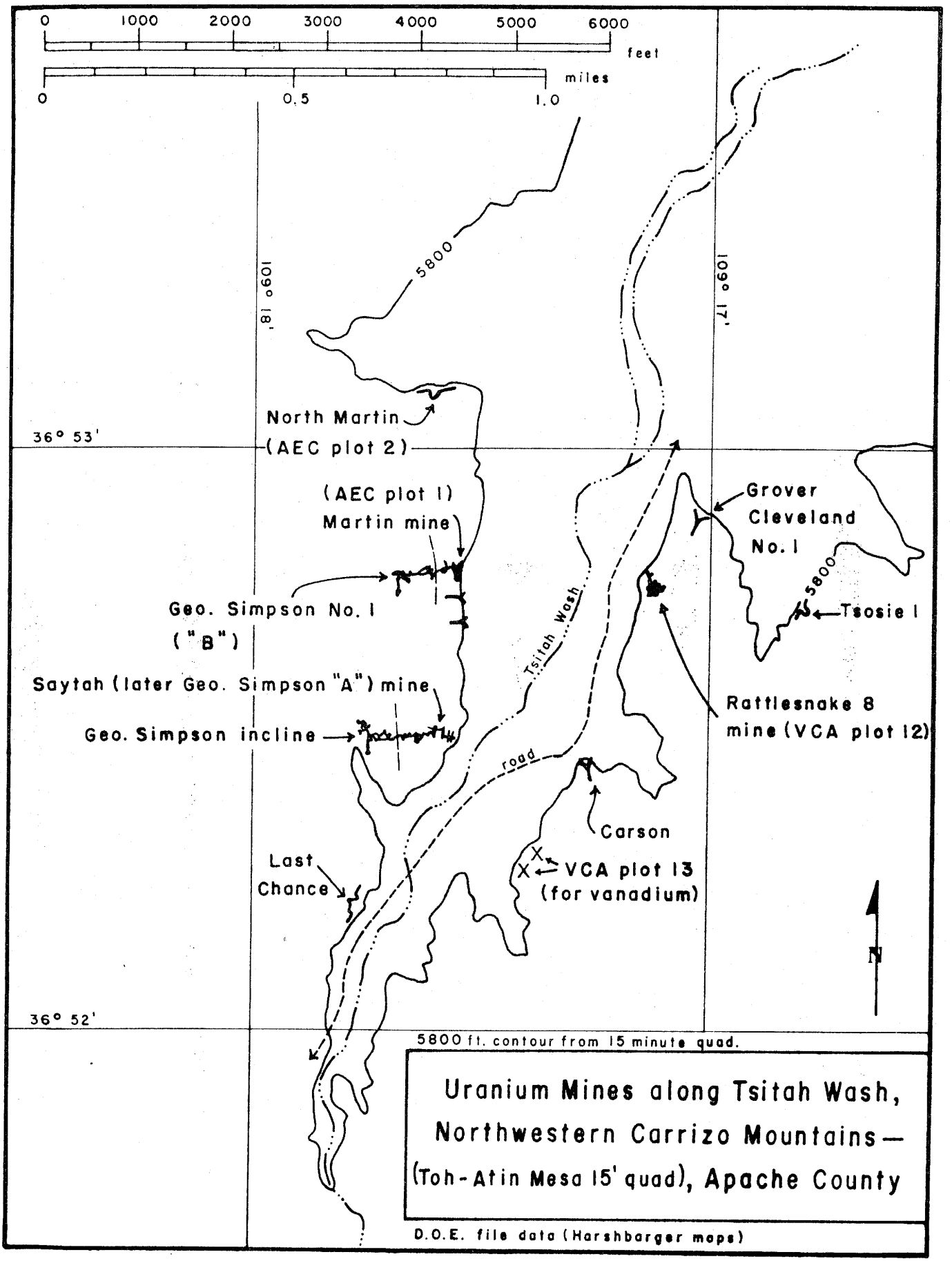
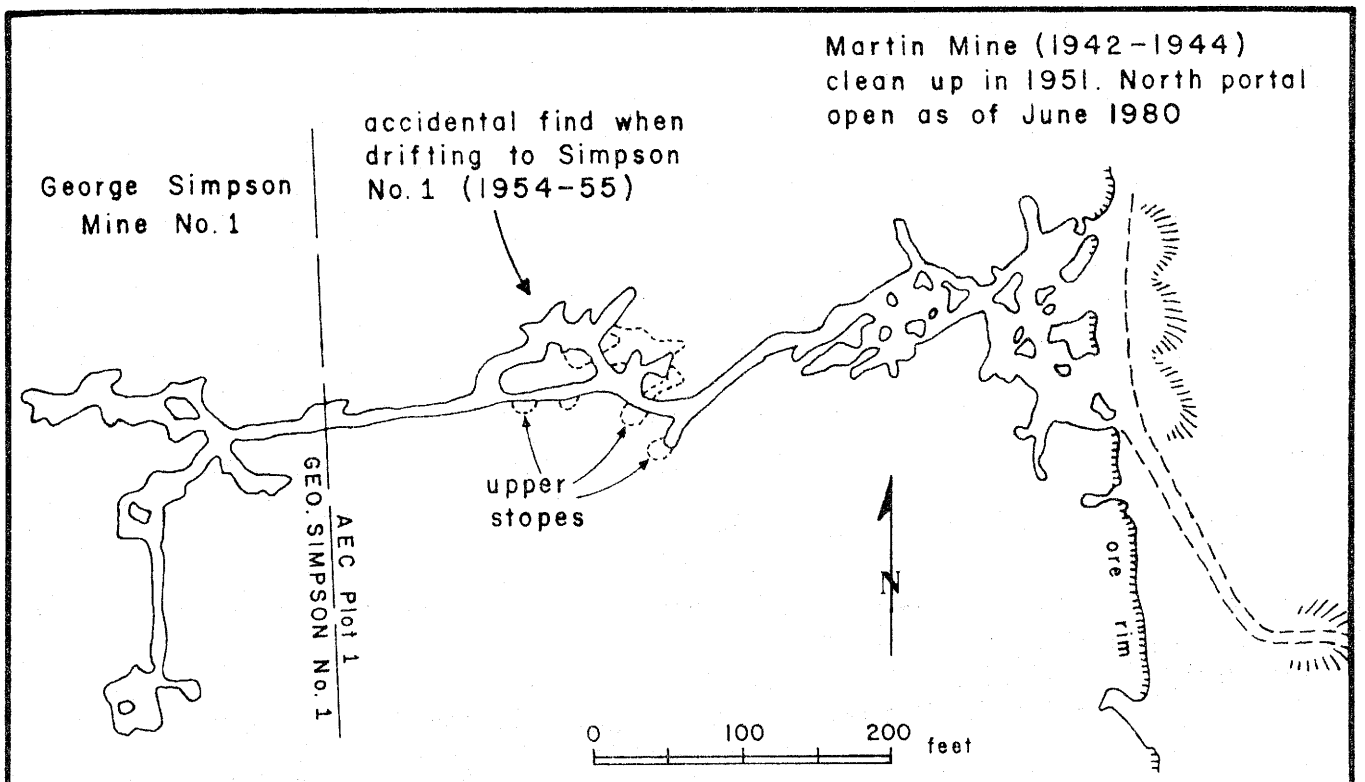
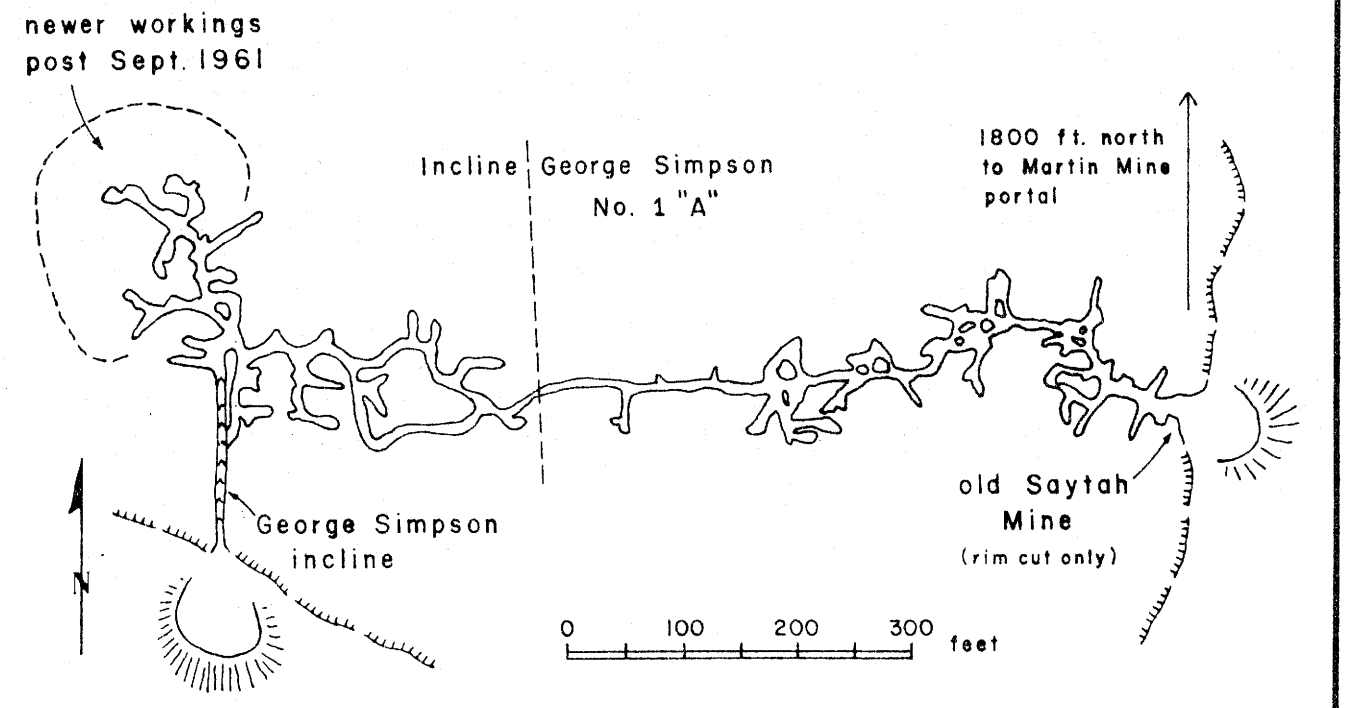

0 1000 2000 3000 4000 5000 6000
feet
0 0.5 1.0
miles
109° 18'
109° 17'
5800
North Martin
(AEC plot 2)
36° 53'
(AEC plot 1)
Martin mine
Geo. Simpson No. 1
("B")
Saytah (later Geo. Simpson "A") mine
Geo. Simpson incline
Tsitah Wash
road
Grover
Cleveland
No. 1
5800
Tsosie 1
Rattlesnake 8
mine (VCA plot 12)
Carson
VCA plot 13
(for vanadium)
Last
Chance
N
36° 52'
5800 ft. contour from 15 minute quad.
Uranium Mines along Tsitah Wash,
Northwestern Carrizo Mountains—
(Toh-Atin Mesa 15' quad), Apache County
D.O.E. file data (Harshbarger maps)

Figure 9



Mine Map — Martin (AEC Plot No. 1) & George Simpson No. 1 "B"
as of 1961

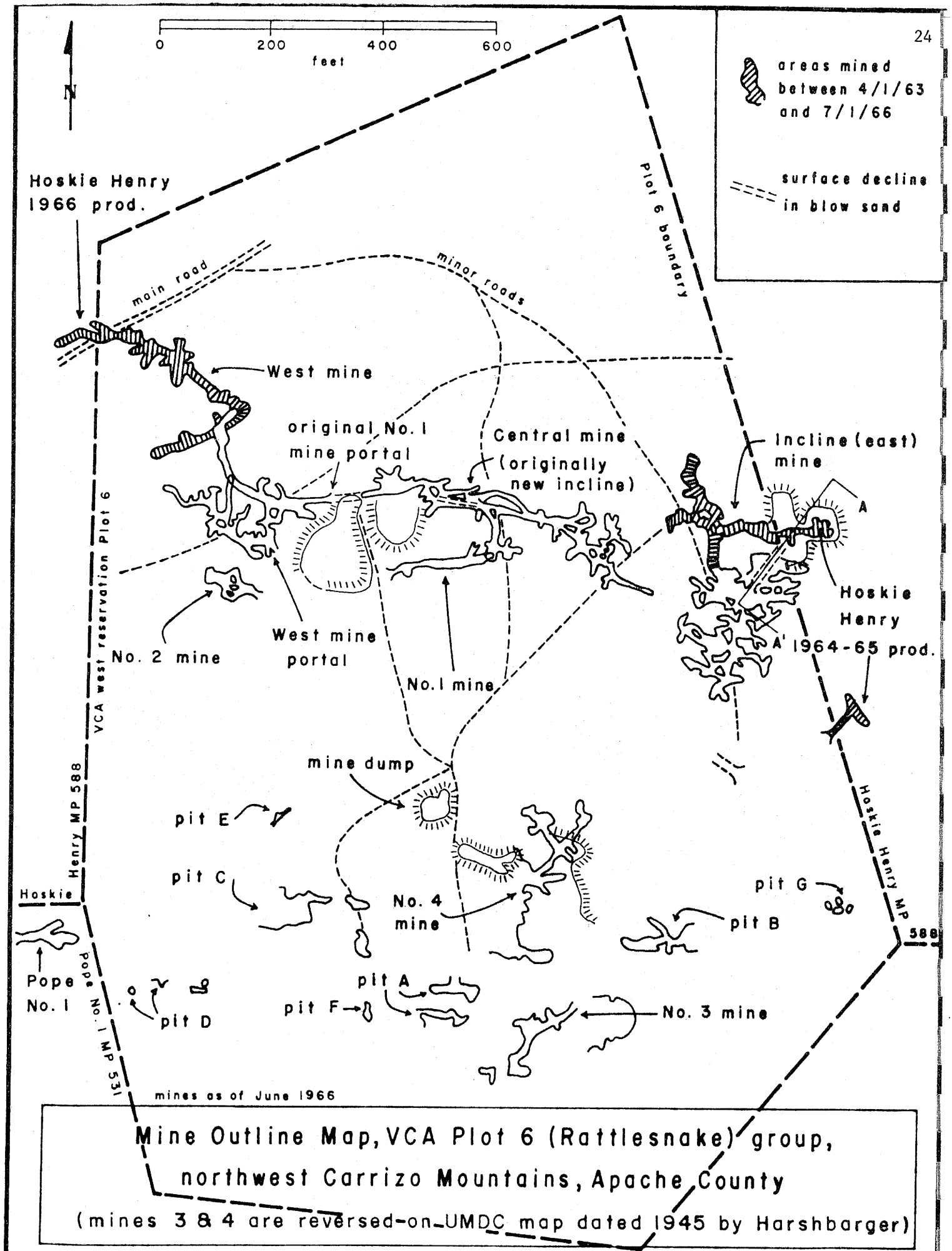
Data from DOE files



Mine Map — Saytah & George Simpson Incline and No. 1 "A"
as of Jan. 1962

Data from DOE files

Figure 10



Mine Outline Map, VCA Plot 6 (Rattlesnake) group, northwest Carrizo Mountains, Apache County

(mines 3 & 4 are reversed on UMDC map dated 1945 by Harshbarger)

Figure 11

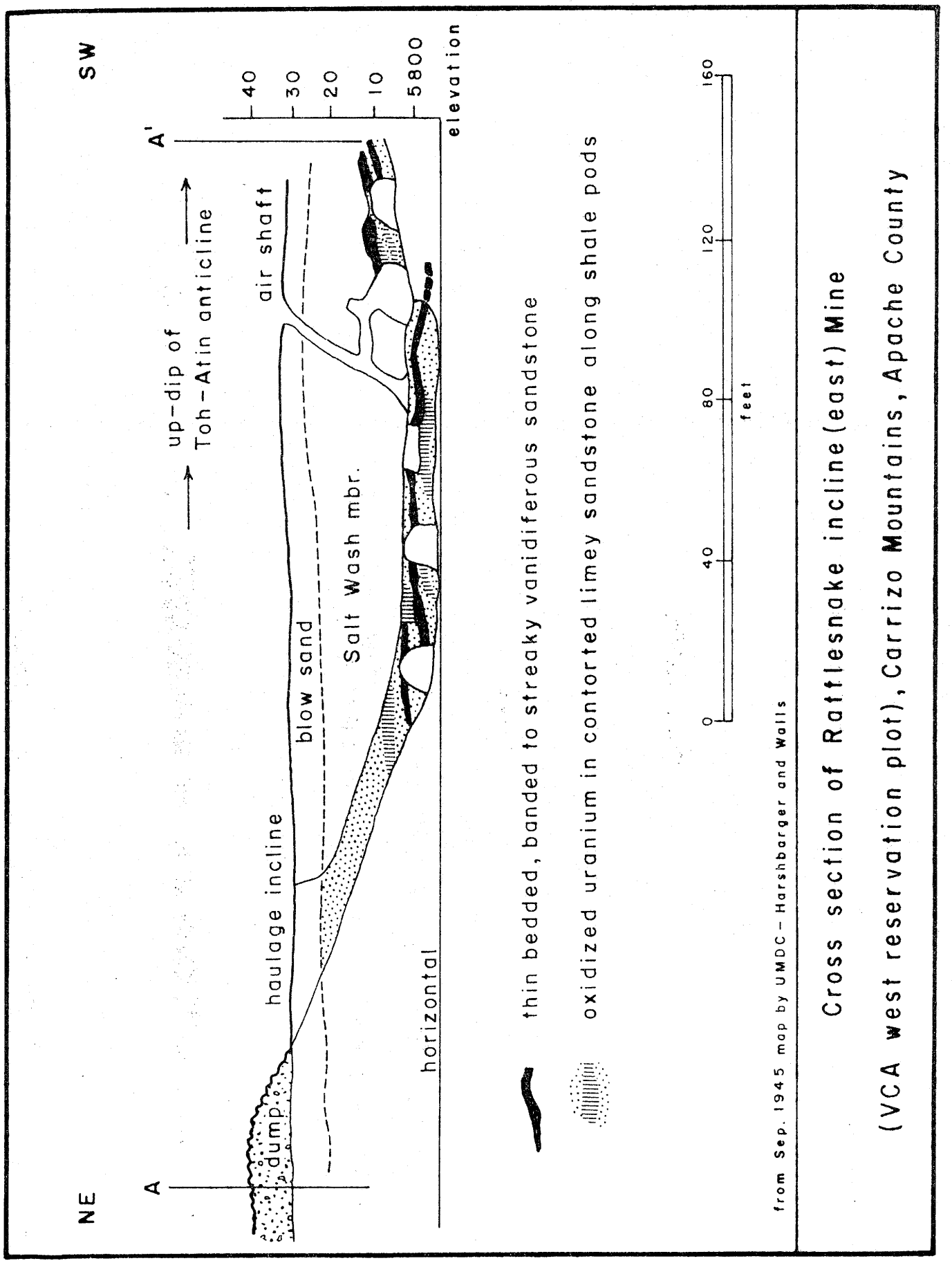
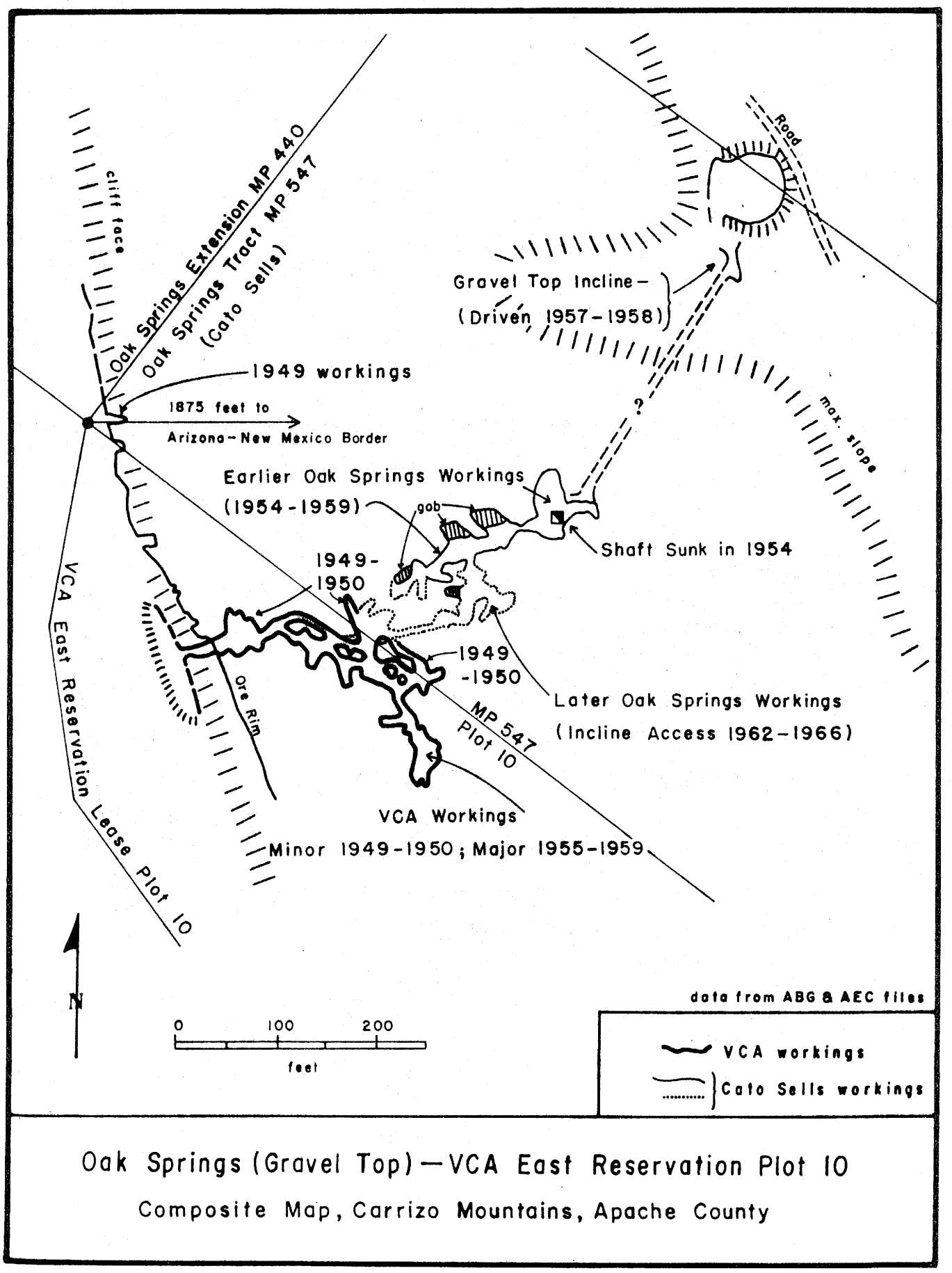

SW
NE
A
A'
elevation
5800
10
20
30
40
up-dip of
Toh-Atin anticline
air shaft
blow sand
Salt Wash mbr.
haulage incline
horizontal
dump
thin bedded, banded to streaky vanidiferous sandstone
oxidized uranium in contorted limey sandstone along shale pods
0
40
80
120
160
feet
from Sep. 1945 map by UMDC – Harshbarger and Walls
Cross section of Rattlesnake incline (east) Mine
(VCA west reservation plot), Carrizo Mountains, Apache County

Figure 12



Oak Springs (Gravel Top) — VCA East Reservation Plot 10

Composite Map, Carrizo Mountains, Apache County

Figure 13

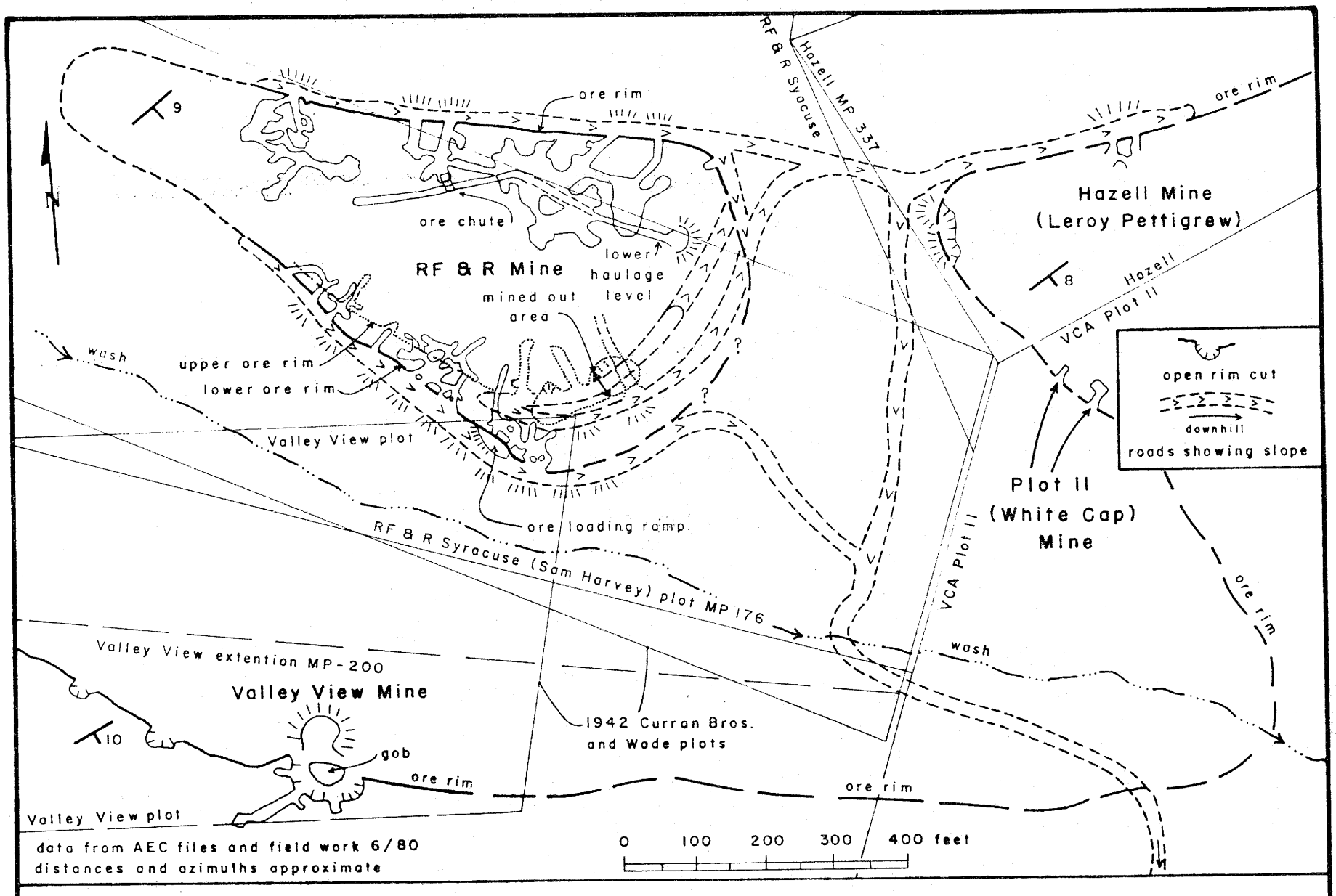


Figure 14

Composite sketch map of RF & R (Syracuse) Mine, VCA Plot II, Hazell Mine and Valley View Mine, east Carrizo Mountains, Apache County

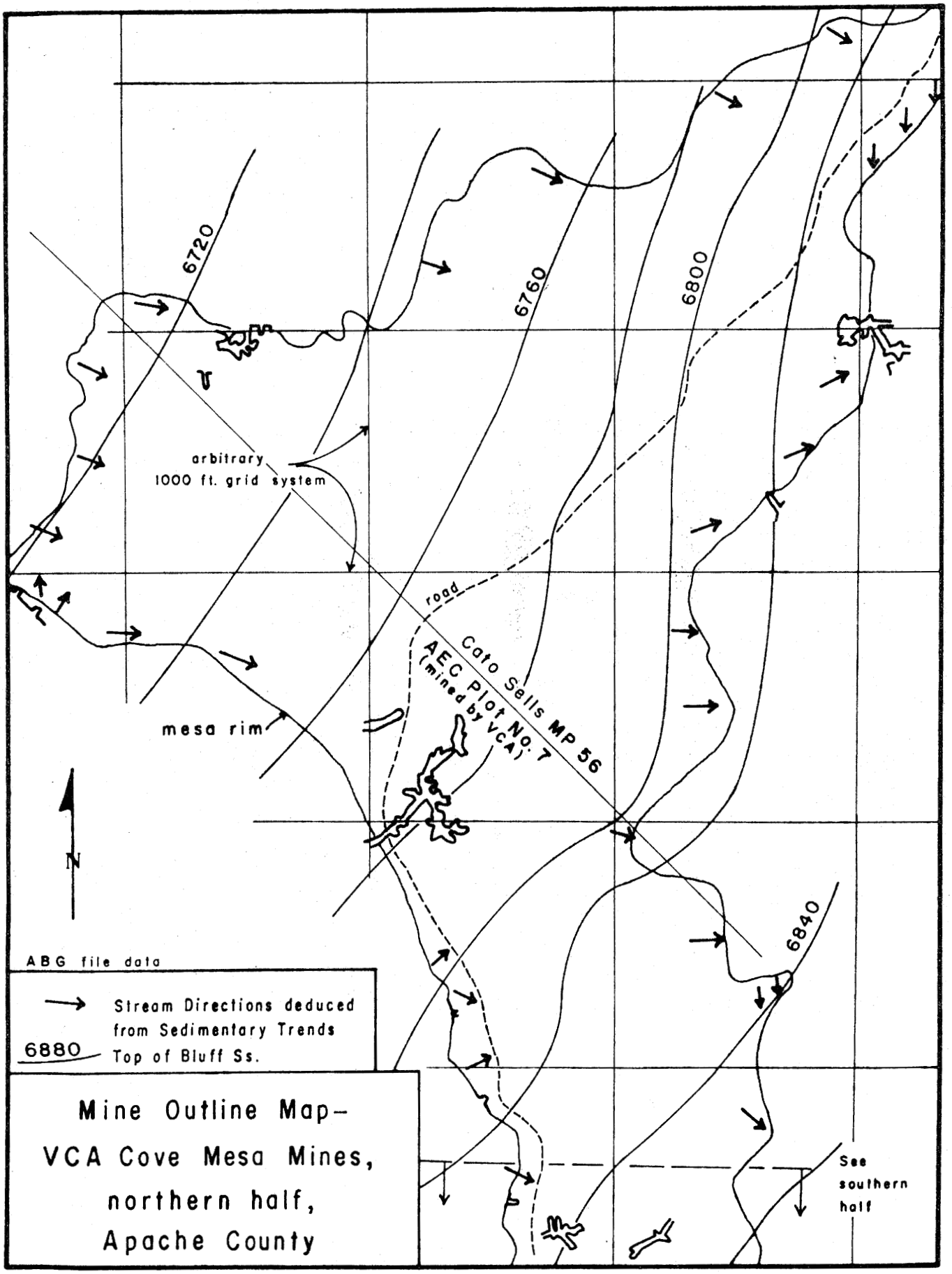

6720
6760
6800
6840
arbitrary
1000 ft. grid system
road
Cato Sells MP 56
AEC Plot No. 7
(mined by VCA)
mesa rim
N
ABG file data
Stream Directions deduced
from Sedimentary Trends
6880
Top of Bluff Ss.
Mine Outline Map-
VCA Cove Mesa Mines,
northern half,
Apache County
See
southern
half

Figure 15a

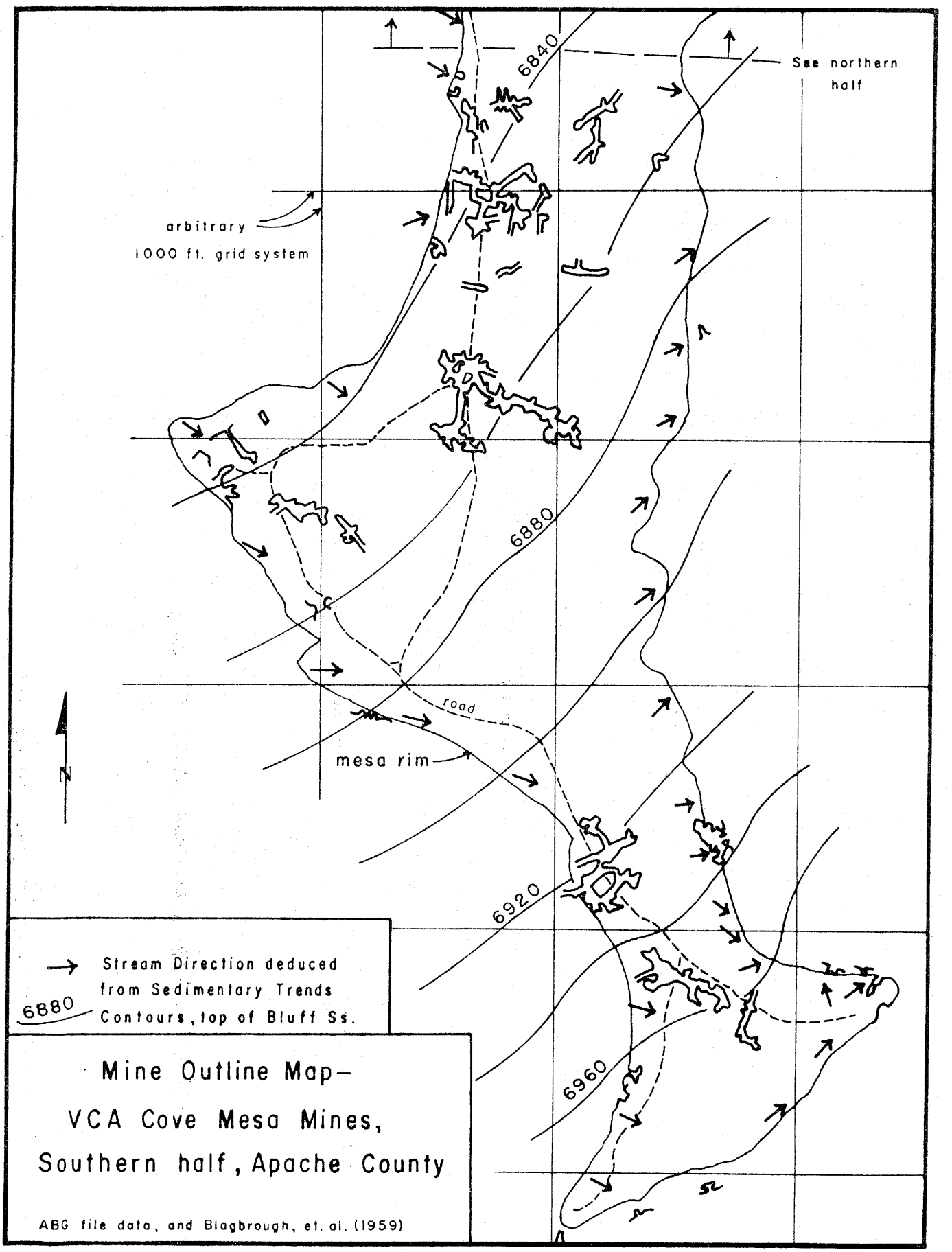

6840
See northern half
arbitrary
1000 ft. grid system
6880
road
mesa rim
N
6920
6960
→ Stream Direction deduced from Sedimentary Trends
6880 Contours, top of Bluff Ss.
Mine Outline Map–
VCA Cove Mesa Mines,
Southern half, Apache County
ABG file data, and Blagbrough, et. al. (1959)

Figure 15b

CHINLE FORMATION

Monument Valley

Uranium was first noted in the Monument Valley region by Gregory (1917) in an area which was later to become Arizona's largest mined uranium deposit, the Monument No. 2 mine. Mining by the Vanadium Corporation of America during 1942-1944 for vanadium was superseded in 1948 by uranium recovery.

Monument Valley uranium ores are found predominantly in paleochannels of the Shinarump Member of the Upper Triassic Chinle Formation, and to a much lesser extent in the underlying Meoenkopi Formation. Shinarump channels were cut into the Triassic Moenkopi and Permian DeChelly Sandstone and filled with muds, sands, and gravels, now represented by 10-250 feet of resistant ledges which cap many of the prominant mesas and buttes of the region. About 800-950 feet of overlying soft Chinle shales have been removed by later erosion of the north-south elongate Monument Upwarp, of which Arizona's Monument Valley is the southernmost flank. (See Mitcham and Evensen, 1955, Figure 1.)

Total production figures from 73 Monument Valley properties indicate the mining of 1,322,000 tons of ore averaging 0.33% U_3O_8 (8,670,000 lbs) and 0.92% V_2O_5 (24,361,400 lbs) between 1948 and 1969. During 4 years, 1953, 1954, 1958, and 1959, the amount of U_3O_8 from the district exceeded 750,000 lbs/year. Much allied production came from equivalent Shinarump paleochannels (Figure 6) in adjacent Utah.

Monument Valley uranium occurrences are discussed by Mitcham and Evensen (1955), Finnell (1957), Evensen and Gray (1958), Witkind (1961), Witkind and Thaden (1963), Young (1964), Malan (1968), and Chenoweth and Malan (1973).

Uranium ores have been mined from the lower parts of the Shinarump channels, especially from scours where the channels are cut especially deep into underlying sediments. The Monument Valley Shinarump channels are filled mostly with pebble conglomerates and sands with abundant woody plant trash and fossil logs. They commonly contain only one ore-bearing scour. In a few mines ore extends beneath the scour bottoms as much as 15 feet into underlying beds. Ore bodies tend to be cigar-shaped and horizontal, parallel to the main channel trend. Length to width ratios vary from 5:1 to 50:1 (Chenoweth and Malan, 1973).

The deposits contain variable amounts of vanadium and copper. V_2O_5 grades range from 0.2 to 0.9% and copper ranges from 0.2 to 2.5%. There is a tendency for vanadium contents to decrease and copper contents to increase from east to west. Further, calcium carbonate is present in the ores as cementing material in sandstone host rock, ranging in content from 1.4 to 10.3%. There is an inverse relationship between calcium carbonate and vanadium contents, but no relationship is apparent between calcium carbonate and copper (Chenoweth and Malan, 1973).

Mitcham and Evensen (1955) list 27 guides to ore positions in Monument Valley Shinarump channels. They suggest that the best ores are confined to low scours, or are found at or downstream of meander bends in channels. Regional structures may influence ores in so far as the lower portions of limbs of regional anticlines and monoclines are more likely to contain ore deposits than higher portions.

Example - Monument No. 2 Mine

Production from this mine started as several different underground-open pit operations, several of which eventually merged, as seen in Figure 17, into a single open pit. Between 1948 and 1967, mines of this group are credited with 767,000 tons of ore averaging 0.34% U_3O_8 and 1.42% V_2O_5 with very low copper values. This makes the Monument No. 2 mine, with about 5.2 million lbs of U_3O_8, the largest uranium mine in Arizona to date. The overall V_2O_5:U_3O_8 ratio is slightly greater than 4:1.

The Monument No. 2 Shinarump paleochannel scour extends for at least 2 miles in a north-south direction within a wider depression or scour about 50 feet deep cut into underlying Moenkopi and DeChelly units. A narrow, inner scour is another 30 feet deep and 700 feet wide. Drilling along scour projections to the north and south indicates the paleochannel does not exist because of post-Shinarump erosion.

The best Monument No. 2 ores are in typical "cigars" or "rods" up to 8 feet in diameter and 100 feet long. Ore is both unoxidized (uraninite, coffinite, montrosite, corvisite, minor iron-copper sulfides, etc.) and oxidized (tyuyamunite, carnotite, hewettite, navajoite, etc.) types which impregnate sandstone voids, replace quartz grains, clay particles and abundant fossil plant debris, and fill vertical fractures which extend beneath the scour base. This latter observation led Finnell (1957) to suggest a hydrothermal source for the ores which rose from depths along en echelon fractures produced in Laramide time. Most other workers, however, subscribe to the groundwater-style ore emplacement hypothesis that envisions movement of ore solutions along Shinarump channelways during the Mesozoic, prior to erosional removal of much of the Shinarump.

Production from the mine was enchanced between 1955 and 1964 by a mechanical ore upgrader situated near the mine which separated a higher grade mud product (0.24% U_3O_8 and 2.6% V_2O_5) from lower grade sands (0.02% U_3O_8, 0.18% V_2O_5) that were discarded. Additional ore was recovered in 1964-67 by heap leaching of the sand residue and some low grade ores.

Cameron-Holbrook Region

Uranium production from 99 properties around Cameron, Coconino County, from the lower part of the Chinle Formation of Triassic age accounts for about 295,100 tons of ore averaging 0.21% U_3O_8 and 0.03% V_2O_5, mostly between 1954 and 1963. This total includes twenty properties in thin sandstone beds in the Chinle Fm. just north of Holbrook, which are credited with 2685 tons of ore (1% of the Cameron total) averaging 0.149% U_3O_8 and at least 0.14% V_2O_5 between 1953 and 1960. This total makes the Cameron region and 4th largest uranium production district in Arizona.

Most of the ores of the Cameron area have been produced from the Chinle Formation, although initial discovery and first production from the area (both in 1950) came from the Ward Terrace (Hosteen Nez) property in the stratigraphically higher Kayenta Formation. Two mines in lower Kayenta beds (Ward Terrace and Yellow Jeep) in the Cameron area produced 182 tons of ore averaging about

0.15% U_3O_8 and about 0.40% V_2O_5 between 1950 and 1957. In the Cameron area, sixty-seven mines in the lower part of the Petrified Forest Member yielded 1,177,500 lbs of U_3O_8, while 27 deposits in the underlying sandstone and siltstone member account for about 62,500 lbs. of U_3O_8 production (Chenoweth and Malan, 1975).

For general references on the Cameron area, see Wright (1955), Bollin and Kerr (1958), Austin (1964), Repenning, Cooley, and Akers (1969), Chenoweth and Malan (1975), Spirakis (1980), and AEC Preliminary Map No. 20.

Repenning, Cooley, and Akers (1969) divide the Chinle Formation around Cameron into (in ascending order) the Shinarump, sandstone and siltstone, Petrified Forest, and Owl Rock Members. The uraniferous units around Cameron are the lower part of the Petrified Forest Member and, to a minor extent, the sandstone and siltstone member (Chenoweth and Malan, 1973). The exact stratigraphic context of the Holbrook area uranium mines is not known, although the mines are in strata above the Shinarump, and beneath the Sonsela Sandstone.

The Petrified Forest ores are within elongate fluvial channelways filled with fine-to medium-grained sandstones containing reworked clay pellets, carbonaceous matter, and silicified-carbonized fossil logs occasionally reaching lengths of 50 feet or more. Ore consists chiefly of secondary uranium-vanadium minerals filling pore spaces in the sandstones and in fossil logs. Within the channelways, the ore tends to occur in abrupt depressions of the channel bottom or at meander bends, and tends to associate with carbonaceous layers. Most ore bodies are encased in an alteration halo composed of bleached sandstone and mudstone (Chenoweth and Malan, 1975). Jack Daniels, and Huskon 4 - Paul Huskie 3 are the largest Cameron deposits in the Petrified Forest Member.

The sandstone and siltstone member mines were developed in thin-bedded, cross-stratified fine-to medium-grained sandstone with abundant carbonaceous trash and fossil logs, in the upper 30 feet of the unit. The Huskon 11 mine is the largest source in the Cameron area from this member.

Figures 18 and 19 illustrate pit outlines of Jack Daniels and the Ramco pits, respectively. These represent the most productive open pits at Cameron. Mining methods at Cameron consisted of open pits to depths of about 150 feet, with small amounts of underground mining from the pit walls to recover additional ore (Chenoweth and Malan, 1975).

Concerning the mineralogy of the Cameron ore bodies, Austin's (1964) detailed mineralogical study states that most ore consists of oxidized uranium species, but fossil logs are found in various states of oxidation. As logs are exposed to oxidizing conditions, pyrite and marcasite alter to hematite, limonite, and iron sulfates, while uraninite and coffinite alter to uranophane, zippeite, boltwoodite, schroeckingerite, and uranocircite. Where primary pyrite and calcite have filled skrinkage cracks in carbonaceous material, they are found replaced by sulfates, especially gypsum and barite (Austin, 1964, p. 75). He accounts for mineralogical "double halos" around some oxidizing logs at certain deposits by a complex oxidation history involving ground water and possibly the downcutting history of the Little Colorado River (p. 76-84). However, with only local exceptions, the Cameron ores are in chemical-radioactive equilibrium.

Austin suggests that the main chemical elements related to the uranium ore zones are U, Ca, Mn, Cu, Mo, Co, Pb, Cd, Ni, and V (Zn notably absent). The best mineralogical guides to uranium ore are the presence of a) blue molybdenum oxide fracture films, b) calcite-gypsum-barite gangue minerals, and c) bleaching of country rock from gray to a yellow or buff color due probably to oxidation of sulfides in protore halos. The Huskon No. 10 and 11 mines contain notable trace amounts of molybdenum and cobalt-bearing minerals.

There are numerous collapse structures recognized around Cameron (Chenoweth and Blakemore, 1961; Barrington and Kerr, 1963), but only one, the Riverview mine, has recorded uranium production (508 tons of ore @ 0.38% U_3O_8). Curiously, the ore came from a peripheral shear zone and blocks of downfallen lower Chinle clastics within the pipe, a structural situation resembling the Orphan Lode. Also curious is the resemblance of the ores (high U, high Cu, very low V) to the Orphan ores much more than the other Cameron ores (intermediate U, intermediate V, some Mo, Cd). Barrington and Kerr (1963) describe in detail some silicified "plugs" intruding the Moenkopi Formation northwest of Cameron which contain bleached halos in Moenkopi beds and peripheral radioactive pyrite-copper anomalies, containing signs of argillic (kaolin to illite) alteration.

The Cameron district has potential for additional uranium deposits, especially east of the Little Colorado River where broad channels in lower Petrified Forest beds can be expected, and in lesser oxidized channelways at slightly greater depth in lower Chinle strata (Chenoweth, pers. comm., 1980). Drilling in 1977-1980 in the area has provided encouraging results for further exploration. Spirakis (1980) suggests that the Cameron district contains additional uranium potential based on a model of subsidence during Petrified Forest time and preservation of abundant organic matter in the sediments due to burial beneath ground water tables, prior to uranium emplacement.

Vermilion Cliffs - Lee's Ferry

Minor production is recorded from the Chinle Formation in the Vermilion Cliffs-House Rock Valley area astride the Colorado River near Lee's Ferry. Production is from both Shinarump paleochannels cut into the Moenkopi Formation, and from the Petrified Forest Member of the Chinle Formation.

Four mines in Shinarump paleochannels (El Pequito, Jimmy Boone, Sun Valley, and Vermilion No. 1) yielded 1212 tons of ore averaging 0.20% U_3O_8 (4759 lbs of U_3O_8), and six mines in lower Petrified Forest sand and mud channel fills (Big Blue, June, Red Wing, Sam, Thomas No. 1, and Tommy) produced 312 tons of ore at 0.22% U_3O_8 (1367 lbs of U_3O_8). Total production from the area is 1524 tons @ 0.201% U_3O_8 between 1954 and 1957. The geology of the ore deposits is very similar to the other Shinarump and Petrified Forest ores from Cameron and Monument Valley. Channel trends in the Shinarump and lower Petrified Forest indicate flow directions toward the NW - NNW (Phoenix, 1957, 1963). Uranium ores from the Sun Valley mine contain very unusual concentrations (to 0.07%) of a water soluble rhenium salt (Peterson and others, 1959).

Figure 20 shows outcrops of Chinle beds and some of the mines and occurrences in the Lee's Ferry area.

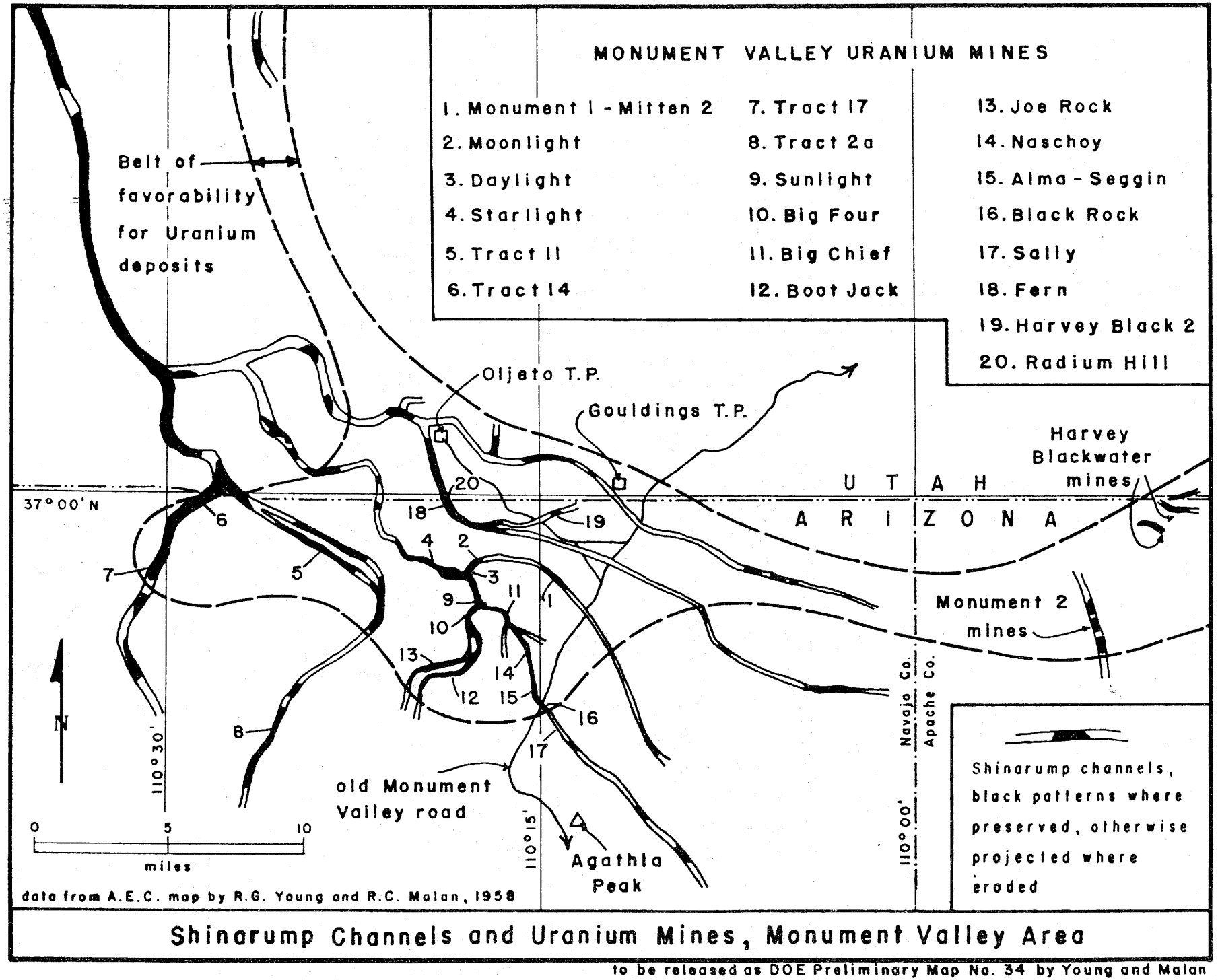
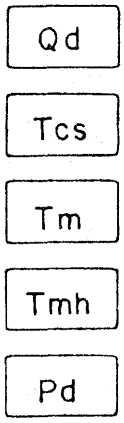


Figure 16

Shinarump Channels and Uranium Mines, Monument Valley Area

to be released as DOE Preliminary Map No. 34 by Young and Malan

Explanation for Figure 17, Monument No. 2 mine



*For new nomenclature see Vaughn (1973), p. 99.

Structural contours drawn on base of Monument No. 2 channel.

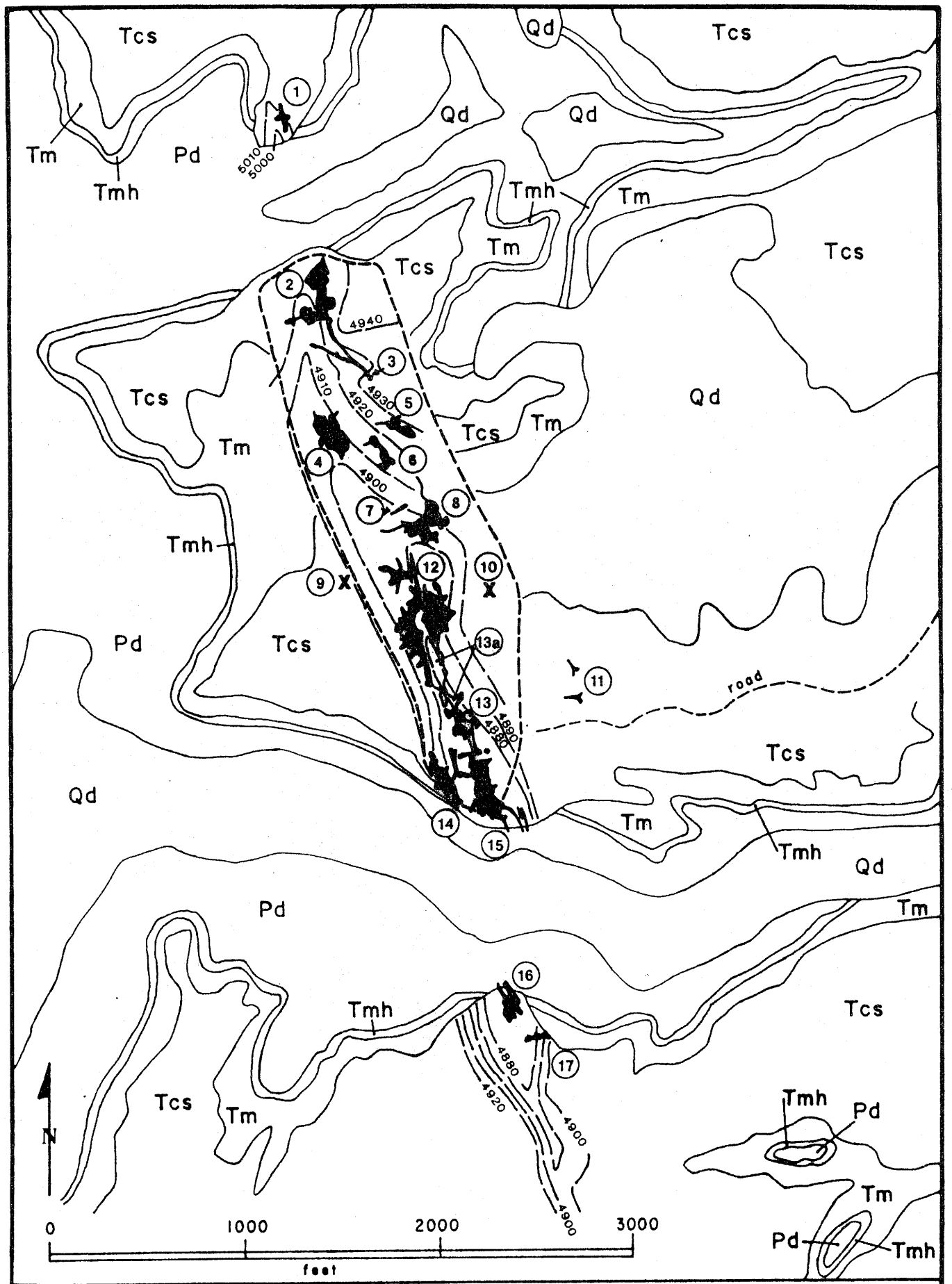
blackened areas are upper level workings
clear areas are lower level workings

open pit mine

Mine Names

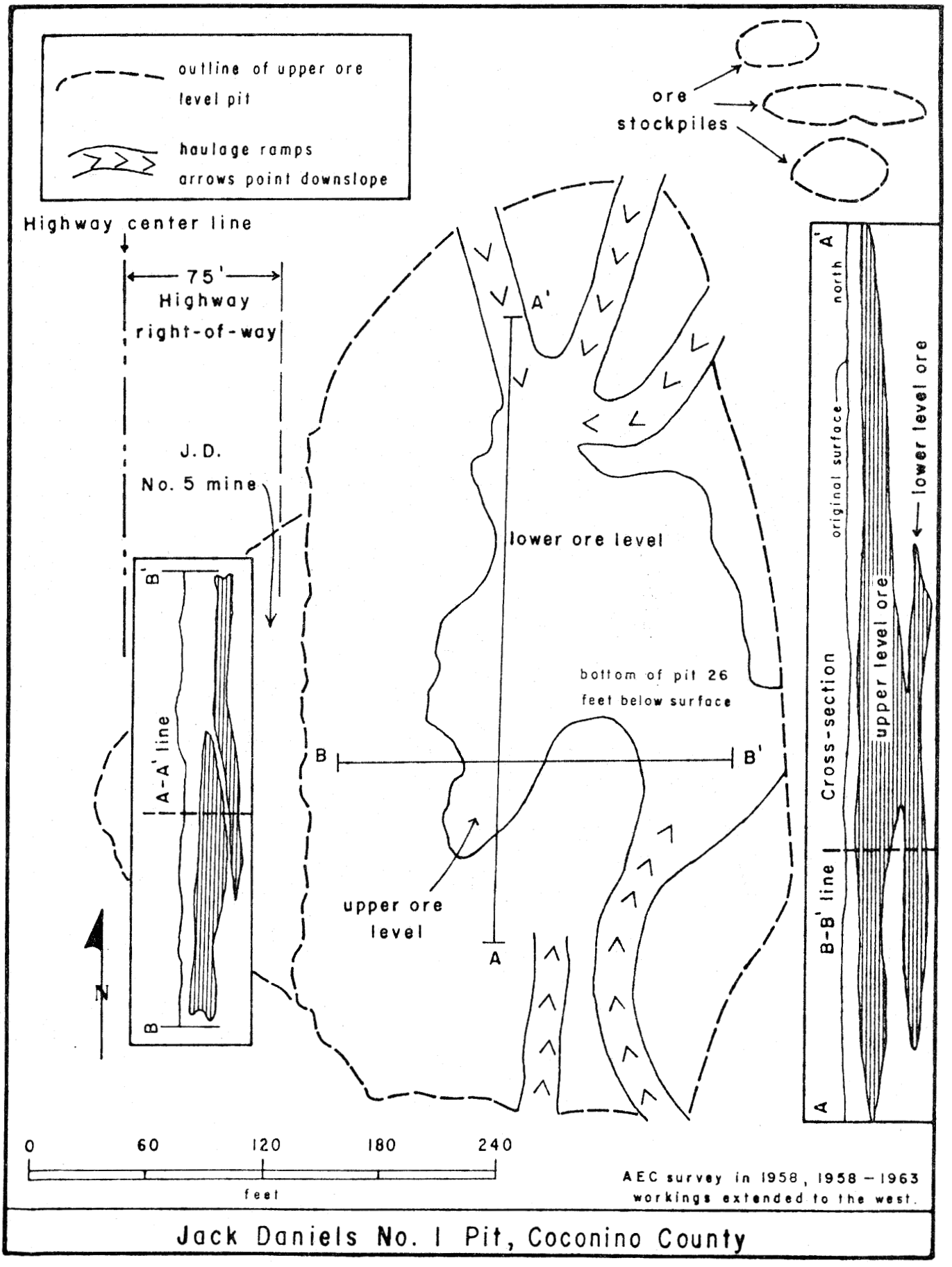
1 John M. Yazzie Mine
2 North workings, Monument No. 2
3 North drifts, Monument No. 2
4 West Red Oxide workings, Monument No. 2
5 East Red Oxide workings, Monument No. 2
6 South red oxide workings, Monument No. 2
7 Incline No. 3, Monument No. 2
8 Central workings, Monument No. 2
9 Cato Sells tract 2
10 Cato Sells tract 1
11 Black and Blackwater mine
12 Incline No. 1, Monument No. 2
13 Incline No. 2, Monument No. 2
13a Incline No. 2, lower workings
14 Bobcat workings, Monument No. 2
15 South workings, Monument No. 2
16 South extension, Monument No. 2
17 Cato Sells tract No. 1 south

Geology and underground workings from Witkind and Thaden (1963).
Open pit outline from AEC guidebook RME-141, p. 2-63.



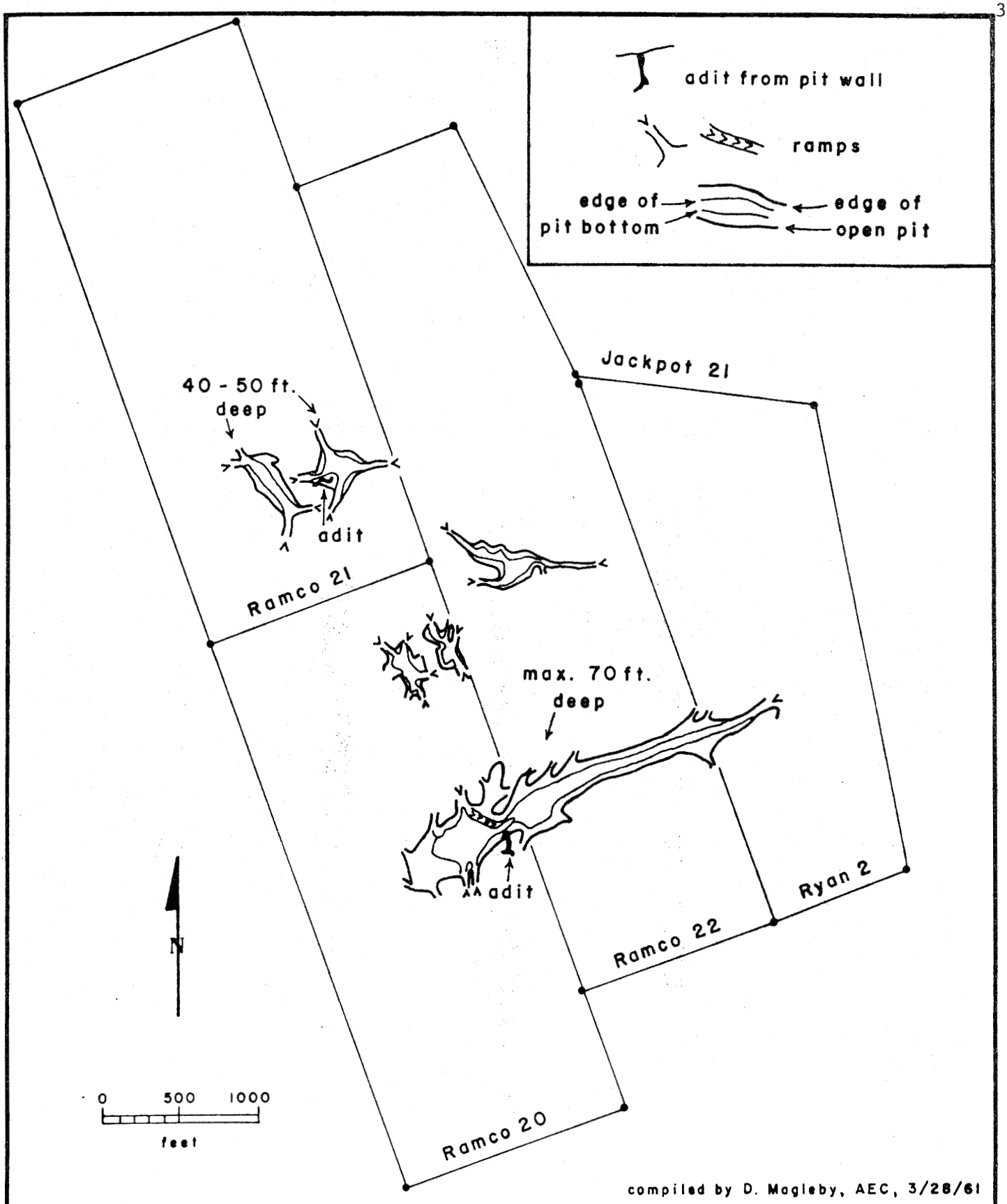
Geology and Mine Development at VCA s Monument No. 2 Mine, Apache County

Figure 17



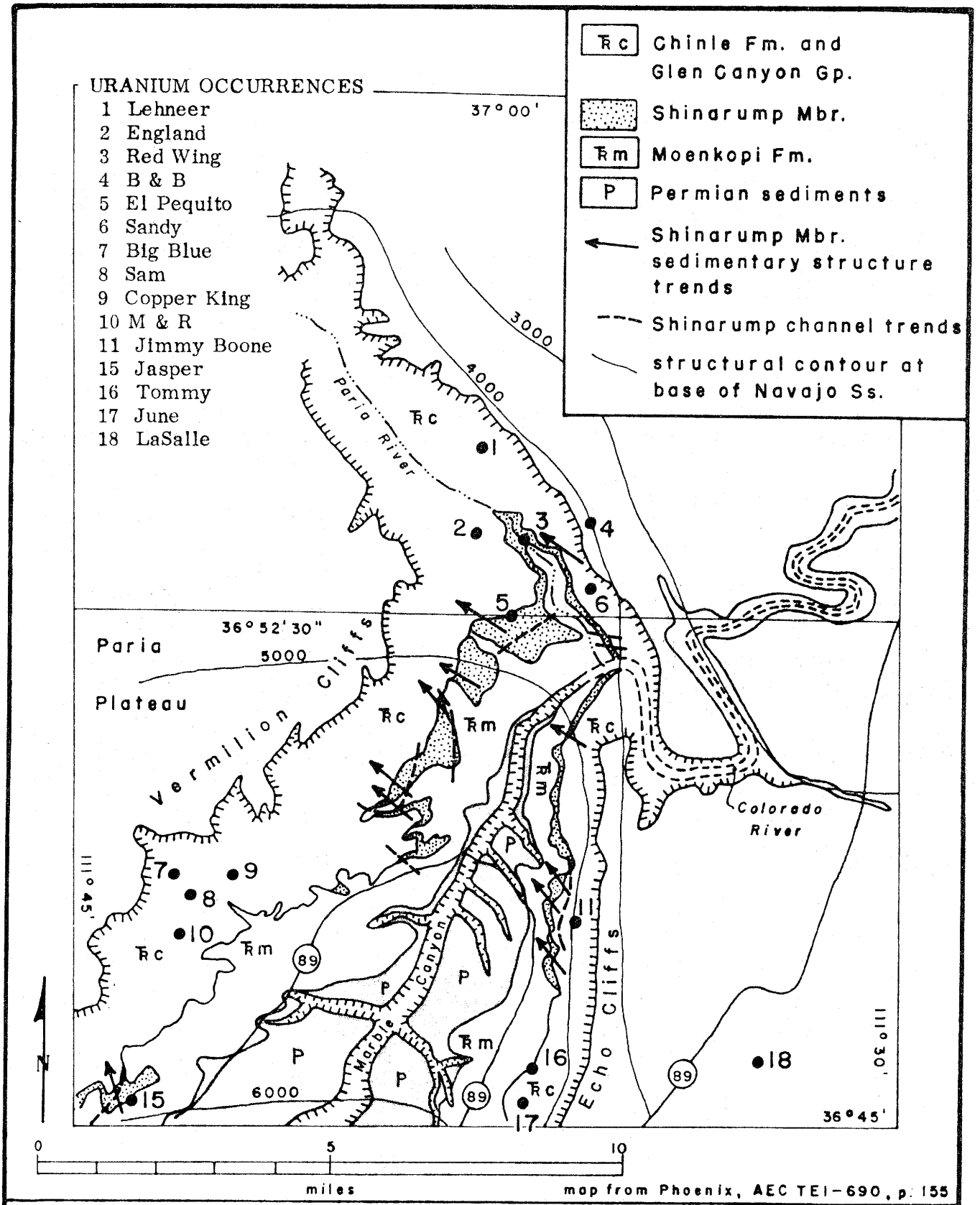
Jack Daniels No. 1 Pit, Coconino County

Figure 18



Pit Outlines, Ramco Pits, Cameron Area, Coconino County

Figure 19



Shinarump Channels, Lee's Ferry-Vermilion Cliffs area
Coconino County

Figure 20

TOREVA FORMATION

Thirteen mines in the upper Cretaceous Toreva Formation (Mesaverde Group) of eastern Black Mesa produced 16,781 tons of ore averaging 0.166% U_3O_8 between 1954-1958 and 1964-1968. An additional 123 tons was produced from two mines in the Salt Wash Member of the Morrison Formation a few miles north of Rough Rock trading post and were included in the Black Mountain-Rough Rock production figures on DOE Preliminary Map No. 31 of 16,903 tons @ 0.17% U_3O_8. Assays for vanadium on the Toreva ores were incomplete, but best indications are of a 1:1 U_3O_8:V_2O_5 ratio for the ores (Chenoweth and Malan, 1975).

General references on this area include DOE Preliminary Map No. 31, Clinton (1956), Repenning and Page (1956), Repenning and others (1969), O'Sullivan and others (1972), and Chenoweth and Malan (1973).

Uraniferous outcrops around Polacca Wash were brought to the attention of the AEC in January 1954. Subsequent ground and aerial surveys in 1954-1956 identified about 25 radioactive anomalies in the Lohali Point-Yale Point area, many of which were subsequently developed into mines. A few anomalies were caused by thorium-bearing heavy mineral placer accumulations in Upper Cretaceous intertidal sand deposits, discussed subsequently by Houston (1956), and Houston and Murphy (1977), who recognized these in association with the Cretaceous seaway throughout the Cordilleran region. See also Bingler (1963) for some northern New Mexico analogs.

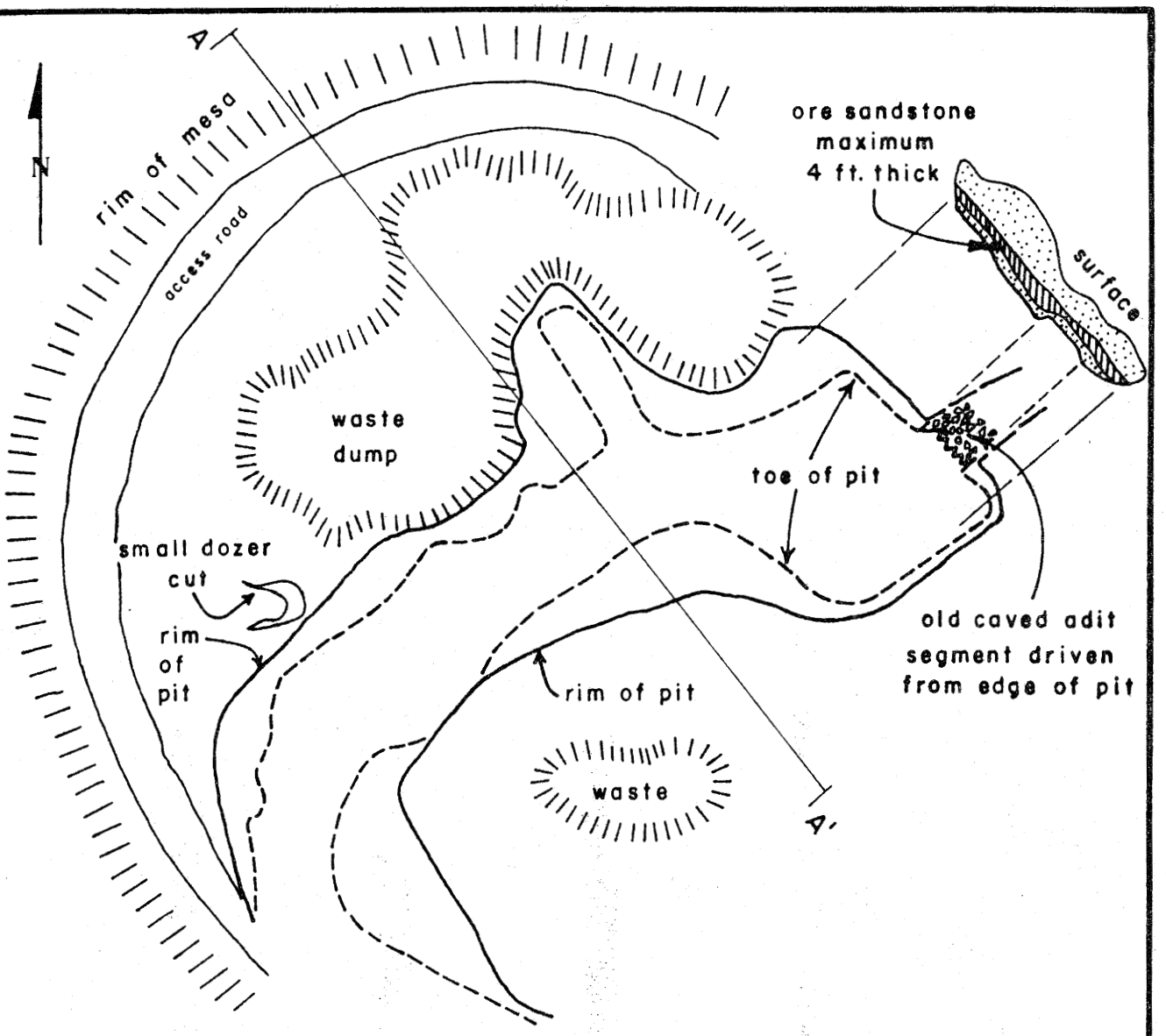
Repenning and Page (1956) subdivided the Upper Cretaceous Mesaverde Group rocks of Black Mesa into three formations. They are, in ascending order, the Toreva Formation, Wepo Formation, and Yale Point Sandstone. These formations represent a complex intertonguing of marine and non-marine beds. See Cooley and others (1969, Figure 4) for a cross-section of Black Mesa stratigraphy and excellent geologic mapping. See also Beaumont and Dixon (1965) for additional geologic mapping in a part of the region.

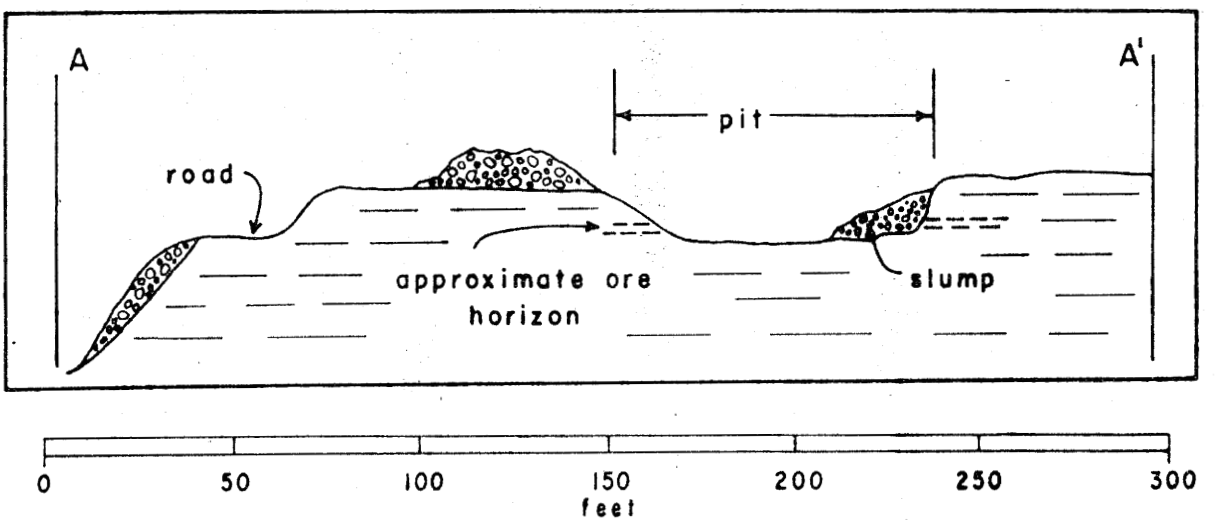
The uraniferous horizons in the Toreva Formation occur in the "main ledge" sandstone, 140-170 feet of fine-to-medium grained noncalcareous sandstone, locally burrowed and micaceous, with lenses of coarse arkosic sandstone, coal, carbonaceous shale, and siltstone in the upper part. Most of the uranium occurs along bedding planes in low-relief channel sands in the upper 40 feet of the "main ledge," disseminated in the sandstone, quite often immediately below carbonaceous lenses. The host unit is described by Chenoweth and Malan (1973) as consisting of fining upward sequences interpreted as migrating point bar deposits with overlying abandoned channel-fill sediments. Facies relationships and channel cross-bedding measurements indicate a sediment source to the southwest, with a general NW-SE trend on paleo-shorelines in these beds. The NURE Gallup NTMS evaluation study concludes that these beds represent a delta-distributary system, one of the few of post-Dakota Sandstone age on the Colorado Plateau. The mined deposits consist of clusters of pods of ore-grade material surrounded by protore. Typical deposits measured 400 x 100 feet x less than 2 feet thick. Most ore was mined by shallow open pits, rim cuts, and in three places by underground methods (Rough Rock slope, Etsitty No. 1, and Claim 7). Uranium minerals include tyuyamunite and metatyuyamunite. Vanadium minerals include vanadium clays, metahewettite, and melanovanadite. Study of paragenesis

at Etsitty No. 1 mine (Clinton, 1956) suggests first the introduction of vanadium clays and $CaCO_3$ (to 0.8% by weight of rock) as cementing agents followed by replacement in the interstitial voids by tyuyamunite.

The three largest uranium producers from the Toreva Formation are, in decreasing order of production, Claim 28 (17,300 lbs of U_3O_8 assaying 0.21%), Claim 10 (15,600 lbs. of U_3O_8 at 0.15%), and Claim 7 (12,500 lbs of U_3O_8 at 0.14%). Together these account for 81% of the U_3O_8 production from the Toreva Formation. The two other most significant deposits are Todecheenie No. 1 (6,100 lbs at 0.22%) and Claim No. 3 (2200 lbs at 0.15%), which make up an additional 15% of the total U_3O_8 produced. Figure 21 is a mine map of the Claim 28 mine.

Clinton (1956) suggests the most significant ore controls in the Toreva Formation to be: a) micaceous or arkosic quartz sandstones in close proximity to lignites or carbonaceous lenses, in shallow relief channel-fill deposits in the general stratigraphic context of interfingering marine Mancos Shale and fluvial (deltaic or shorline) Toreva sands and lagoonal deposits; b) localization of ore bodies at the sharpest bends in paleochannel directions, as indicated by cross-bed directions; and c) a NW-SE trending zone that lies on the steepest-dipping portion of the NE limb of the Black Mountain anticline-SW limb of the Rim syncline structure. This last point resembles that of W. L. Stokes on the ore controls of the northwest Carrizo Salt Wash mines (USAEC RME 3102, 1951), where he suggests response of stream directions and gradients in Salt Wash time to structural movements on nearby anticlines. However, the method by which the structures in these two cases act as ore controls is not confirmed. There is yet no direct evidence that there was structural movement contemporaneous with Toreva sedimentation whereby control of channel directions or placement of point-bar deposits was actually localized with respect to the fold structures seen today. However, Peirce and Wilt (1970, p. 18) note that stratigraphic thinning of overlying Wepo beds on Black Mesa may be related to structural bowing of the Maloney syncline during Wepo time. An equally probable hypothesis, at least in the Toreva (and Morrison) situation, is that postmineralization folding of the strata and subsequent erosion and stream cutting has merely exposed the mineralized areas and made discovery easier. Much of the folding may be Laramide in age; some of it could be Oligocene-Miocene in age, based solely upon intense tectonism in the Basin and Range country to the south during this time.





mapped in 1958 by AEC, additional mining in 1966–1968

Claim 28 Mine, Black Mountain area, Apache County

Figure 21

BRECCIA PIPES

Breccia pipes are perhaps the most enigmatic of the Arizona uranium occurrence types. Those occurring on the Colorado Plateau are approximately vertically oriented chimney-like masses filled with brecciated, heterogeneous assemblages of sedimentary rocks derived from strata which have been displaced downward into the breccia pipe. Nearly one hundred pipes are known in northern Arizona, but uranium has been produced from only five. Of these, all but one have had less than 10,000 lbs of U_3O_8 production (Chapel, Ridenour, Hack Canyon, and Riverview), while the fifth (Orphan Lode) has been a major Arizona producer with production totaling nearly 4.4 million lbs of U_3O_8. Orphan production is exceeded in Arizona only by the Monument No. 2 Mine in Apache County. Because of the track record of the Orphan, exploration for more pipe uranium occurrences is continuing in the Grand Canyon-Arizona strip country. Certainly, many pipes contain radioactive anomalies, while perhaps the majority in this region are barren of mineralization at the surface. Methods such as detailed gravity surveying are being used to peer through superficial cover rocks in hopes of delineating buried pipes. Figure 22 indicates the geographic setting of the known pipes in the Grand Canyon region. Some of these are exposed in apparent WNW-trending groups or clusters where the Grand Canyon erosion event has stripped away cover rocks to expose the Coconino Sandstone-to-Redwall Limestone stratigraphic interval. Almost certainly, other pipes remain hidden in adjacent areas. The majority of the Grand Canyon pipes are found in the sedimentary units above the Mississippian Redwall Limestone. Frequently, their presence is indicated on aerial photographs by a bleaching to very light colors of red or red-brown clastic sediments. Barrington and Kerr (1963) describe analogous structures in the general Cameron area.

The only association of Plateau breccia pipes and attendant Cu-U minerals with any volcanic rocks known to this author is at the Copper House No. 2 claim of Mohave county, where a basalt dike underlies a gossen or iron-stained breccia zone which in turn is related to bleached radioactive Supai beds. The basalt is likely late Cenozoic in age, and may or may not postdate the Cu-U mineralization here.

Exploration continues for buried pipe structures, especially in the region north of the Grand Canyon. In December 1980, Energy Fuels Nuclear announced (Paydirt, No. 498, published at Bisbee, AZ) the discovery of a new breccia pipe about a half mile west of the Hack Canyon mine (Figure 23) in Mohave county. Drilling results indicate a possible 500,000 tons of uranium-copper ore in pipe fill. With a conservative grade of 0.3% U_3O_8, this represents 3 million pounds of U_3O_8. Ore shipments from the new Hack mine are going to Blanding, Utah starting in December 1980.

During 1979-1980, radioactivity associated with copper staining of surficial Kaibab Limestone in the Willaha-Anita area between the Grand Canyon and Williams (Coconino county) received some drilling attention, with the ultimate targets probably being buried breccia pipes such as the Orphan Lode. At least three companies have drilled an estimated two dozen holes. A strict Orphan Lode model would place major mineralization in Supai and Hermit beds, perhaps 1200 feet below the surface. This Kaibab surficial mineralization may also indicate that the breccia pipe phenomena of the region affected rocks at least as young as Kaibab limestone.

Example - Orphan Lode Mine

Many published reports have dealt with the complex origin and mineralization at the Orphan Lode, located near the tourist center along the south rim of the Grand Canyon. See Magleby (1961), Granger and Raup (1962), Kofford (1969), Gornitz and Kerr (1970), Bowles (1977) and Boyden (1978). Figuer 24 is a cross-section through the Orphan pipe, showing its approximate known vertical extent and overall mine development. Figure 25 shows plan views of the 245 and 400 foot levels in the mine. The following discussion is taken from the above sources.

The Orphan Lode claim was located in 1891 for surficial copper showings and was prospected intermittently for copper until about 1910. There may have been no actual production of copper from the mine. The claim was patented in 1906, with the papers being signed by President Theodore Roosevelt. The Grand Canyon was made a National Monument in 1909. In 1953, Golden Crown Mining Company acquired mining rights on the property, following the discovery of uraniferous minerals at the mine by H. Granger of the USGS in 1951. The company constructed an aerial tramway from the pipe outcrop to the canyon rim in 1955. Regular production began in 1956. Production was limited by the 1,000 ton/month capacity of the tramway. Late in 1959 first ore was removed by hoisting through a newly completed 1600 ft deep shaft and 1400 ft cross cut. A bill was passed by Congress in 1962 to allow the mining company (Western Equities since 1961) to mine newly found ore on National Park land, adjacent to the claim, in exchange for NPS ownership of the Orphan property 25 years hence, in 1987. Mining was continued from 1962 to 1967 by Western Equities, and 1967 through 1969 by the Cotter Corporation, which still controls mining rights. Most of the ore through 1969 was shipped to the Rare Metals mill in Tuba City.

The Orphan pipe surfaces in the lower Coconino Sandstone, 1000 feet below the rim of the canyon, and maintains a mean diameter of 230 feet down through the Hermit Shale. It then flares out symmetrically in the downward direction to a mean diameter of 400 to 500 feet in the upper Supai Formation. Vertical drilling suggests that the pipe bottoms near the middle of the Redwall Limestone, since lower units down to the Tapeats Sandstone beneath the mine appear undisturbed in a single deep drill hole.

Where mined, the materials filling the pipe were derived only from units above. Coconino Sandstone blocks have fallen as much as 275 feet below the Coconino base, and blocks of Hermit Shale beds have collapsed over 300 feet down to the 500 ft mine level. No volcanic material, Precambrian rocks, or lower Paleozoic rocks have been identified anywhere in the explored portions of the pipe, indicating only net downward transport of materials presumably due to some kind of collapse, perhaps provoked by solutioning of the underlying Redwall Limestone. Multiple collapse events appear to have occurred, since there are several "pipe within pipe" structures, separated by roughly concentric annular shear zones.

The pipe fill may be separated into breccia (containing blocks of recognizable Hermit, Coconino, and Supai lithologies), and massive sand fill, some of which has been partially calcified (calcite, with some dolomite and siderite filling intergranular spaces). Most of the loose sand fill was derived from the Coconino Sandstone.

The outer pipe wall is a sharp contact. Extensive color bleaching of the surrounding in situ rocks is noted for several feet beyond the pipe wall.

Briefly, there are two main types of ore occurrence in the mine, annular ring (includes "A" ore body of Figure 24) and interior pipe fill ("B" ore body). The "B" ore occurs in the highly fractured and brecciated central interior of the pipe. This ore extends from near the surface outcropping of the pipe to about the 450 ft level. Kofford believes the "B" body lies within an interior "pipe-within-pipe" which was displaced downward with respect to the "A" ore body. The annular ring ore is generally concentrated near the perimeter of the pipe, especially just below the level where the pipe constricts in the upward direction. It has been found downward to near the 550 ft level. In more detail, the annular ring occurs in (1) the shear zone marking the pipe boundary, especially above the Hermit-Supai contact, where it was mined as the high-grade "A" ore body, (2) the breccia just inside those shears, and (3) the disturbed and undisturbed rocks just outside the pipe in the Supai Formation. Outside the pipe, most of the annular ring ore is stratigraphically confined to certain sandy layers in a ring zone surrounding the pipe averaging 6-50 ft wide, and is controlled by placement of annular fractures surrounding the pipe. The annular ring ore appears to bottom out on top of a shale bed in the Supai Formation. In general, more ore occurs in areas having a greater intensity of shearing. High grade ore from the annular ring consists of uraninite intergrown with red earthy hematite, and fine-grained pyrite-chalcopyrite.

Uranium occurs chiefly as uraninite in interstitial intergranular fillings and veinlets following shear zones along with numerous other minerals of iron, copper, lead, zinc, nickel, and cobalt. Some molybdenum, arsenic, silver, maganesium, and barium minerals were also introduced. More than 60 minerals are reported for the mine.

Both sulfide and oxidized mineral assemblages are recognized. The detailed mineral investigations generally conclude that there was, in most part, a rapid, simultaneous precipitation of the sulfide components. The oxidized components may have been formed during the late Cenozoic Grand Canyon cutting event, and, more particularly, during the creation of the Esplanade surface inside the canyon (Bowles, 1977). This surface is a bench formed at the contact between the Hermit Shale above and the Supai Formation below.

Mineral zoning within the pipe is recognized, both in a lateral and vertical sense. The core of the pipe is mostly pyrite and uraninite, whereas the margins contain uraninite with a complex mixture of chalcocite, tennantite, various Ni-Co arsenides, and galena. The galena is of "common lead" composition (i.e., not recently separated from parent uranium) according to Miller and Kulp (1963). Although pyrite and marcasite are distributed throughout the vertical extent of the pipe, uranium content of ore generally increases upward in direct proportion to galena content. The sulfur in the sulfides has a highly fractionated isotopic composition which is much more similar to bacterially produced sedimentary sulfides than usual hypogene sulfide systems.

Kaolinite and illite (1 Md_1, minor 2 M_1) are the only clays associated with mineralization, and hence true arillic alteration may not be present

(Gornitz and Kerr, 1970). Fluid inclusion studies indicate temperature of formation of calcite in the pipe fill of 60-110°C. Miller and Kulp (1963) report sphalerite equilibration temperatures of not above 90°C.

Isotopic ages by various uranium-lead methodologies produce complex, discordant patterns for time of mineralization at the Orphan Mine. Gornitz and Kerr (1970) report age attempts of Miller and Kulp ranging from 87 to 402 m.y., with their best estimate for a minimum age of mineralization being 140 m.y. Miller and Kulp (1963) had originally reported "best" ages of 100-120 m.y. based upon their calculations of U-Pb systematics, including a hypothesized one or two-stage lead-loss model. Each lead loss episode hypothetically involves the dissolution and reprecipitation of "new" uraninite.

The origin of the Orphan ores remains enigmatic. We think that (1) the pipe formed by collapse into a solution cavity formed in upper Redwall Limestone, and (2) low-temperature copper-uranium mineralization was emplaced into permeable fissure systems and porous sandstone pipe fill, along with probably bacterially-derived sulfide sulfur, probably during the Jurassic-early Cretaceous time interval (120-140 m.y. ago). Major unanswered questions include the reason for the localization of the ores near the pipe constriction at the base of the Hermit Shale, the direction from which the mineralizing solutions came, the role in localizing uranium of carbonaceous materials found in the pipe (Kofford, 1969), and the thickness and lateral extent of Mesozoic cover rocks over the Grand Canyon at the time of mineralization.

Finally, one might consider a possible relationship between uranium mineralization during the late Jurassic - early Cretaceous at the Orphan Lode (as deduced by uranium dating) and the large amount of stratabound uranium-vanadium ore in the late Jurassic Morrison Formation of the Four Corners region, which is known to have sediment source areas to the west and south, in the general direction of the Grand Canyon region. It is possible that chemical components of both the Orphan and Morrison ores were transported northeastward in groundwaters or supergene solutions derived from Mogollon highlands volcanic sources in Morrison time or pre-Dakota time, and subsequently chemically fractionated into Cu-U and V-U-Cu components and precipitated in their respective environments. In this model, the stratigraphic lid that overlies both these deposit types is the regional truncation surface that underlies the Dakota Sandstone.

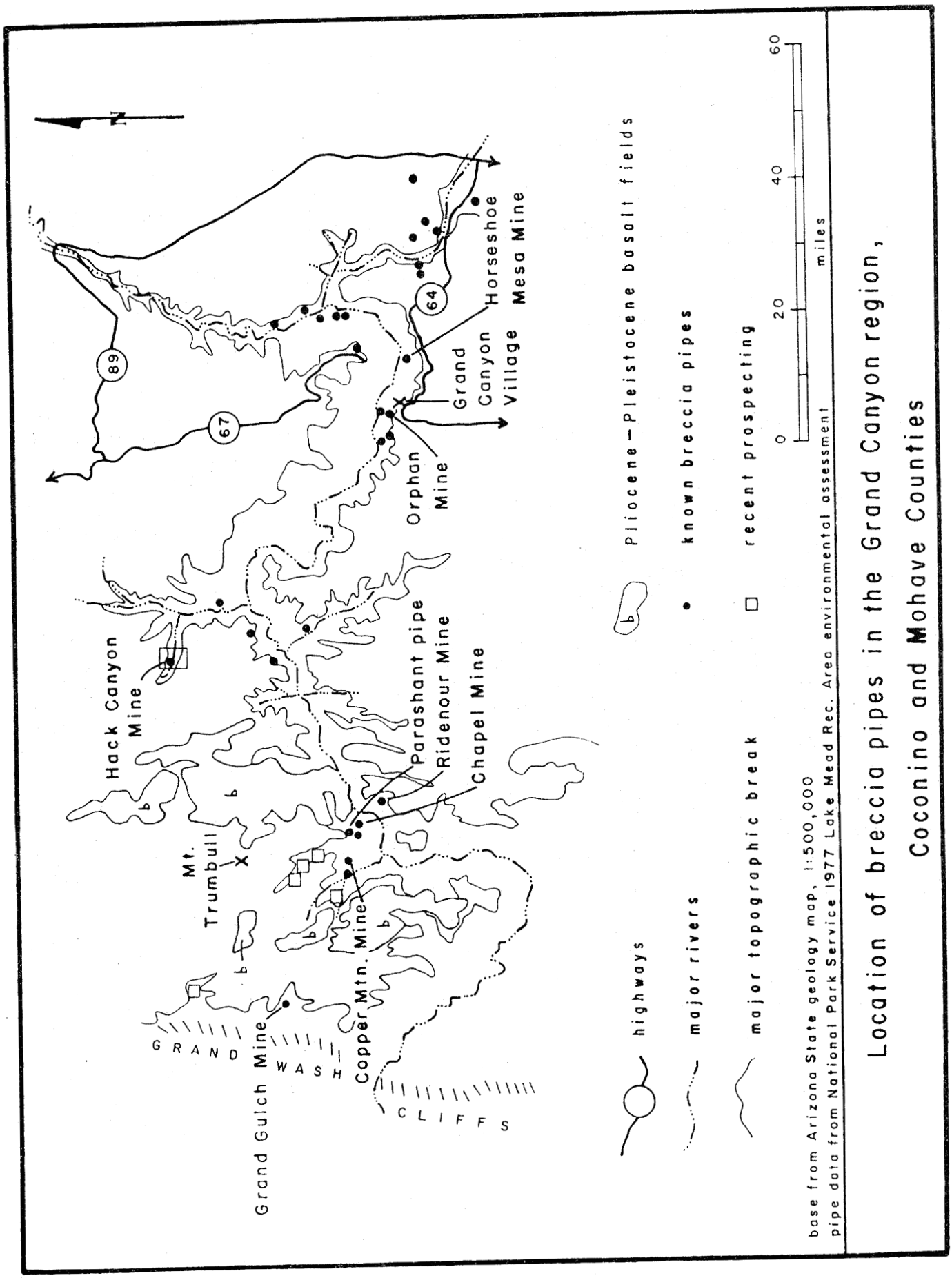
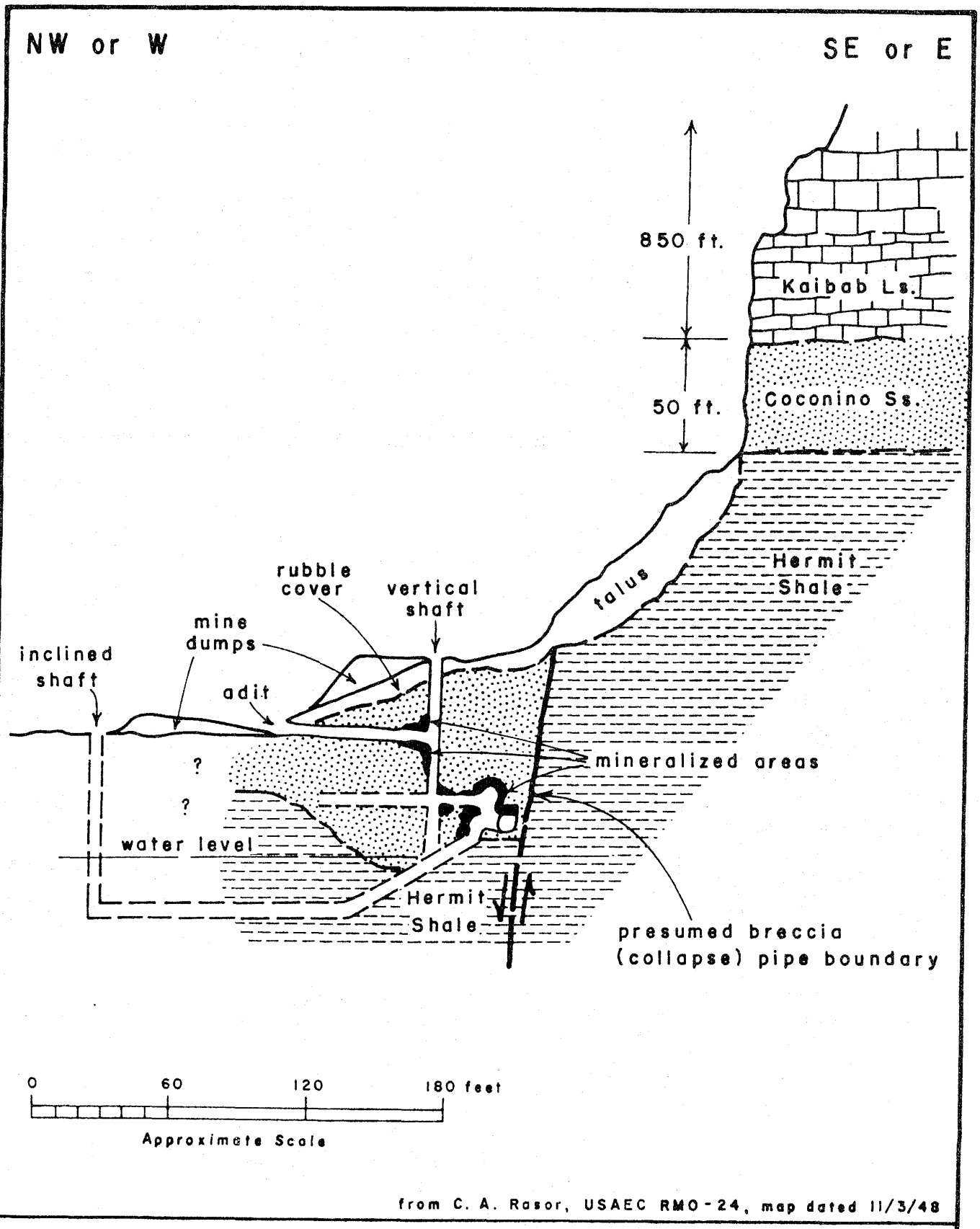
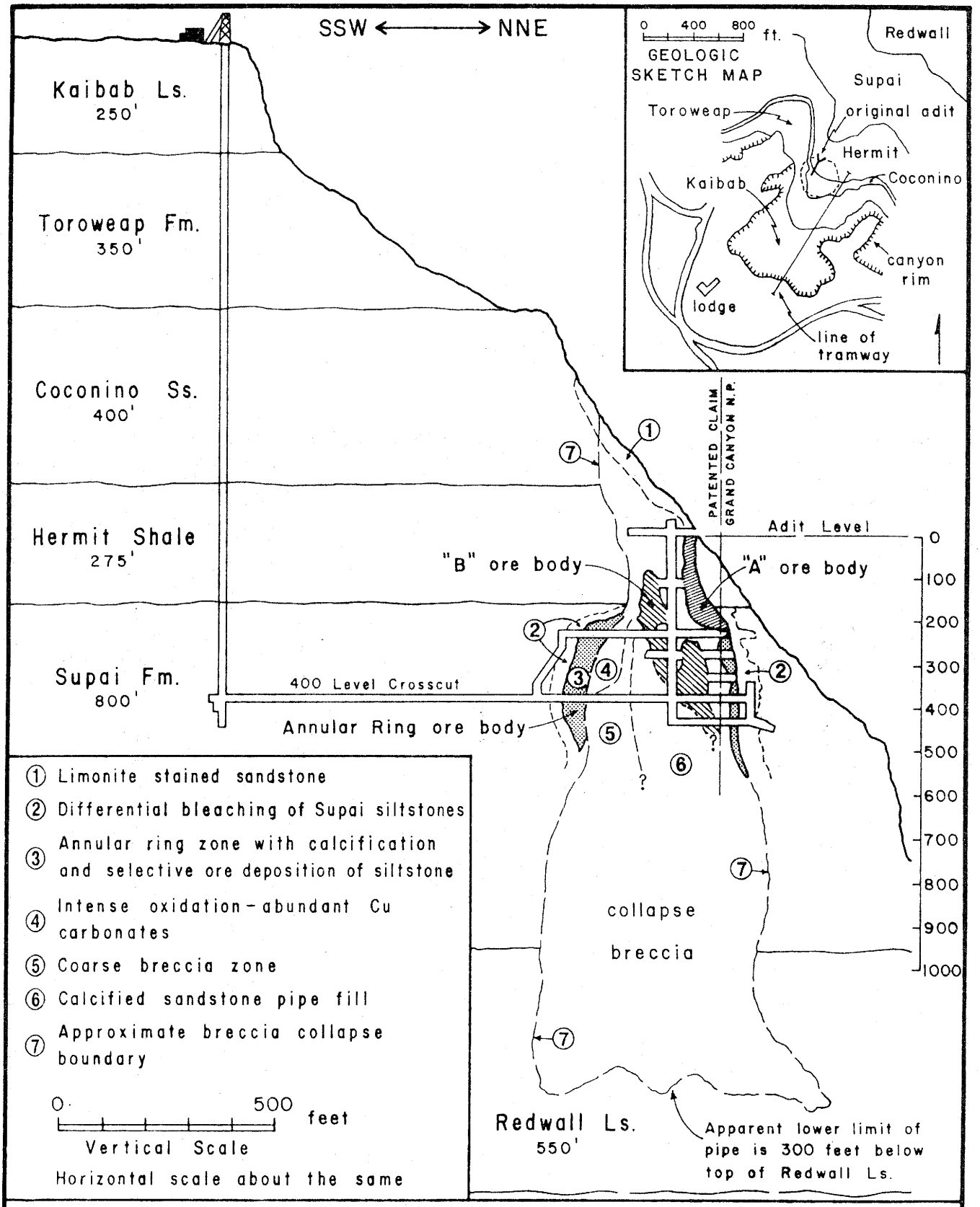

N
89
67
64
Horseshoe Mesa Mine
Grand Canyon Village
Orphan Mine
Hack Canyon Mine
Parashant pipe
Ridenour Mine
Chapel Mine
Mt. Trumbull
Copper Mtn. Mine
Grand Gulch Mine
GRAND WASH CLIFFS
highways
major rivers
major topographic break
Pliocene–Pleistocene basalt fields
known breccia pipes
recent prospecting
0 20 40 60
miles
base from Arizona State geology map, 1:500,000
pipe data from National Park Service 1977 Lake Mead Rec. Area environmental assessment
Location of breccia pipes in the Grand Canyon region,
Coconino and Mohave Counties

Figure 22



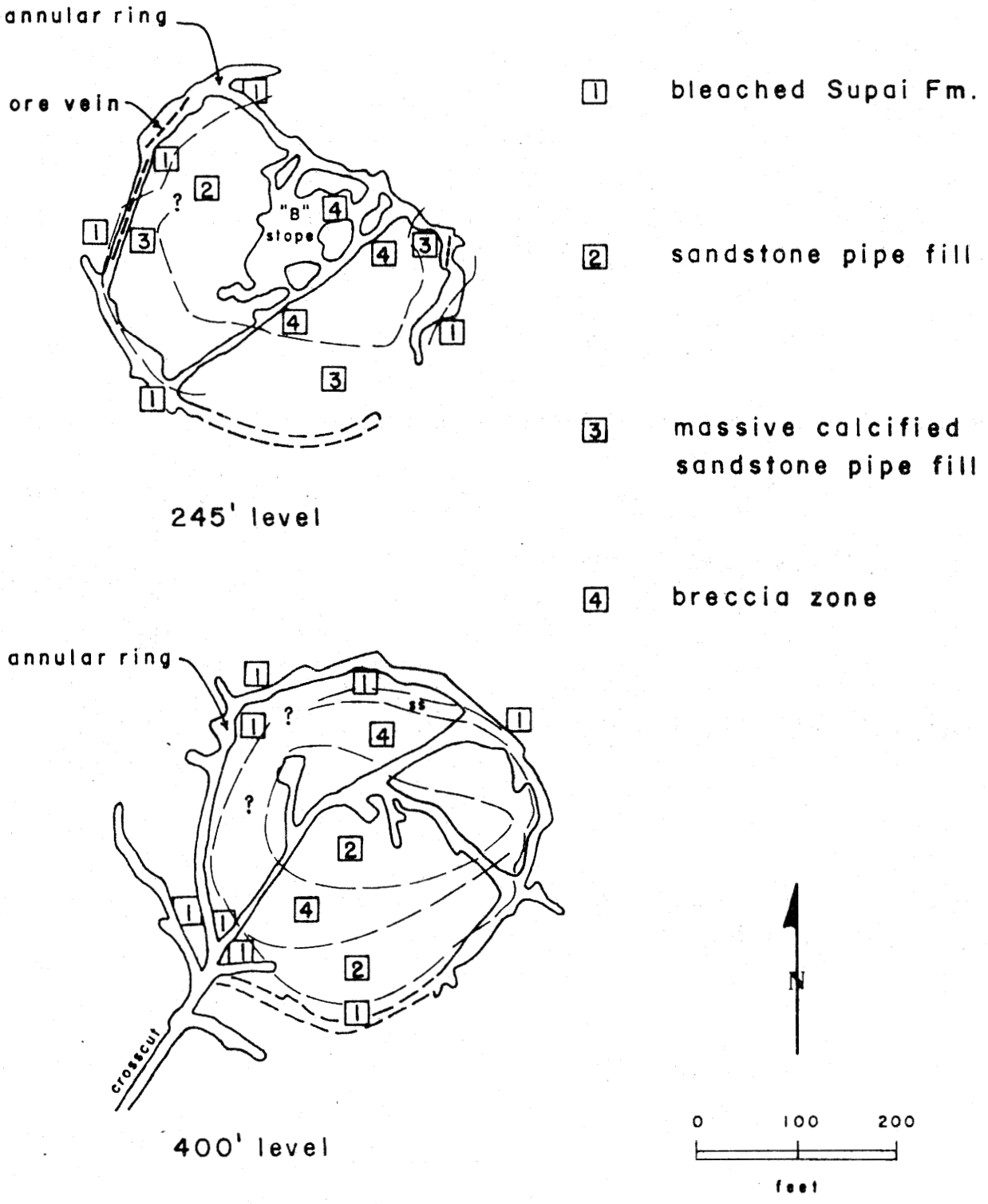
Generalized Cross Section through Hack Canyon Mine, Mohave County

Figure 23



Cross-Section of Orphan Lode, Grand Canyon National Park, Coconino County — composite of several published and unpublished maps, including Kofford (1969) and Gornitz and Kerr (1970).

Figure 24



Plan View of 245' and 400' levels, Orphan Lode
from Gornitz and Kerr (1970)

Figure 25

HOPI BUTTES

Uranium was discovered in the Hopi Butte volcanic field of Navajo County in the early 1950s , with only one claim, the Morale, having yielded ore-grade material. Much uranium-related geologic work in the Hopi Buttes during the 1950s was discussed in open-filed USAEC TEI reports by Eugene Shoemaker, and summarized by Shoemaker, Roach, and Byers (1962). See also Lowell (1950). The USGS, in cooperation with the Bureau of Indian Affairs (BIA), did supplemental geology, petrology, and drilling studies during 1978-1980 which will appear in the NURE Flagstaff and Gallup NTMS folio evaluations (available for public inspection in Grand Junction as of January 1981). A summary of this work appears in Wenrich-Verbeek and Shoemaker (1980). The details below follow from these discussions.

The Hopi Buttes volcanic field consists of about 300 diatremes and associated flows and tuff beds contained in a circular field about 20 miles in diameter. The volcanic rocks of the field, where dated by K/Ar and paleontologic methods, range in age from 4 to 8 m.y. old. By all available evidence they erupted through a lacustrine environment which had already deposited varicolored lakebeds of the Bidahochi Formation in what is now called Hopi Lake. The diatremes and their associated tuffs and flows are seen to rest on top of these lakebeds. The uraniferous lakebeds are deposited inside the diatremes. The volcanics are depositionally overlain in the eastern part of the field by a fluvial (and aeolian?) sandstone (uppermost member of the Bidahochi Formation according to Shoemaker et al., 1962). The Bidahochi lakebeds rest upon Jurassic Wingate Sandstone in the southern part of the Hopi Buttes area, and upon younger Dakota Ss, Mancos Shale, and Mesaverde Group rocks of Upper Cretaceous age in the northern part.

Petrologically, the Hopi Buttes volcanic rocks are classified as limburgites and monchiquites, grading northwestward to minettes. These rocks have lower silica contents (<47%) and higher Na, K, Ti, and P contents as compared to "normal" continental alkali basalts of the southern Colorado Plateau. They also are notably high in Ag, Ba, Sr., Y, Zr, and U, with an average of 4 ppm U as compared with 1 ppm average for the continental basalts. They also generally contain primary $CaCO_3$, present as included masses and veinlets.

The diatremes are funnel shaped with sharp inward-dipping contacts with Bidahochi or older wallrocks. Spatter flows and coeval limburgite tuff distal facies compose the outer portion of the diatremes, with the diatreme interiors filled with brecciated debris produced from collapse and infilling following the phreatomagmatic diatreme-forming eruptions. This infill is composed of blocks of limburgite tuffs, flow rocks, and Wingate Ss and other older wall rock material. Precambrian clasts are uncommon except in local circumstances.

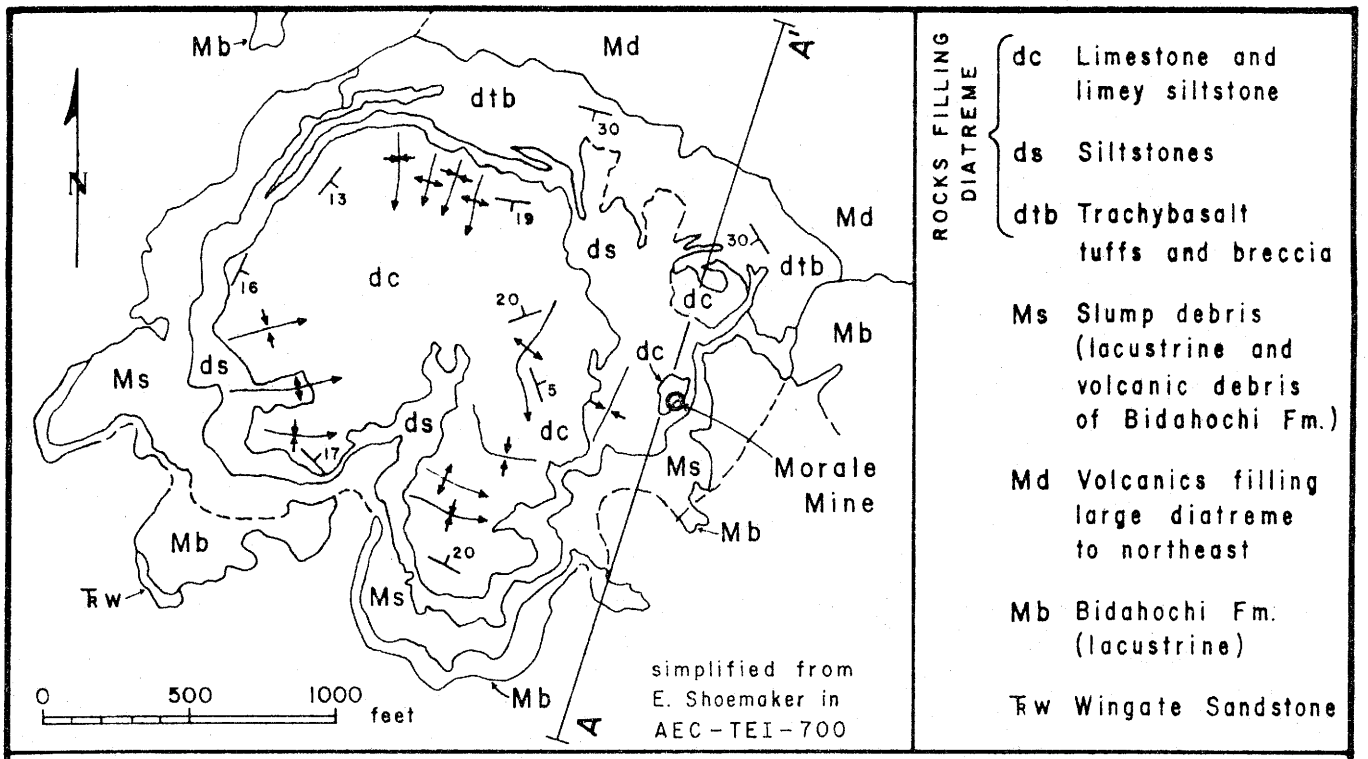
After explosion and collapse of the central vent, the diatremes stood with bowl-shaped depressions which filled with up to 200 feet of mudstones and travertine-like carbonate layers, along with some rhyolitic air-fall ash beds which were being erupted from vents in the Hopi Buttes field. However, it is not clear if these later sediments were also deposited outside the diatremes, perhaps in a still-extant Hopi Lake, and were later removed in all areas except atop the diatremes by the erosion event that left the Hopi Butte diatremes standing as resistant"plugs". Alternately, the sediments could have

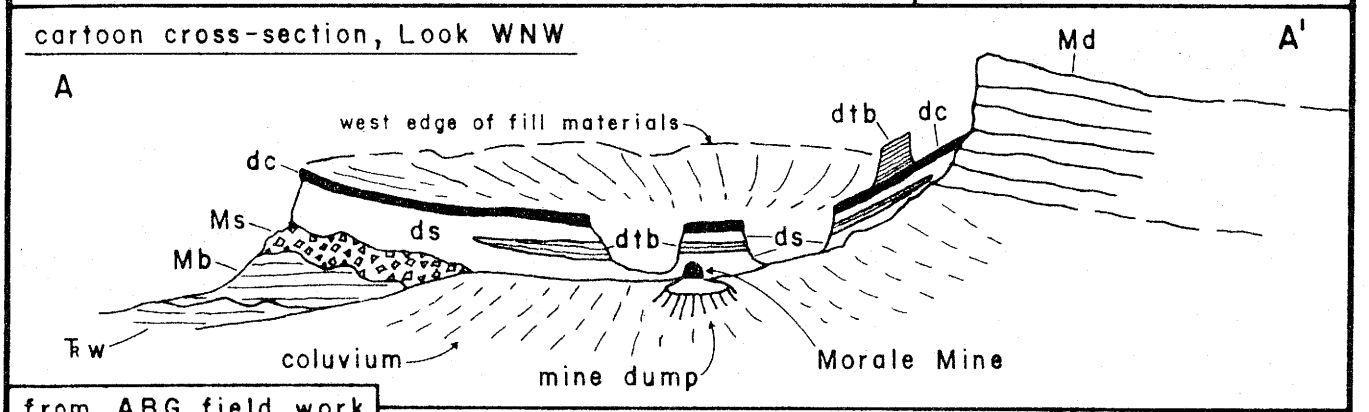
been originally confined to individual ponds inside the diatremes, at a time when Hopi Lake was drying up. A question also arises concerning the origin of the bowl-style symmetrical inward dips of the sediments. They nonconformably overlie the volcanogenic collapsed infill and have flat dips near the center, and progressively steeper dips outward towards the diatreme margins. In places, 20-30° inward dips on shales (which at one place at Coliseum diatreme contain a fish fossil) suggest some post-sedimentation diatreme collapse may have occurred. If so, this post-sediment collapse could be a contributing reason for the preservation of these uraniferous sediments only inside the diatreme bowls, since only there were they protected from erosion because of resistant volcanic bowls surrounding them.

The "perched" diatreme infill sediments are the sole host for the 35 known uranium occurrences of the Hopi Buttes. Twenty of the occurrences in infill deposits contain radioactivity levels 5 times background. No anomalous radioactivity has been noticed at any Hopi Butte eruptive center that lacks these diatreme sediments. The most recent USGS work suggests that the limestone layers in the sediments resemble hot spring travertines and contain characteristic high concentrations of phosphate, sulfate, Ba, Sr, U, Se, Co, Ni, etc. These observations suggest a mineralization model involving thermal waters associated with the diatremes which supplied uranium to the diatreme sediments.

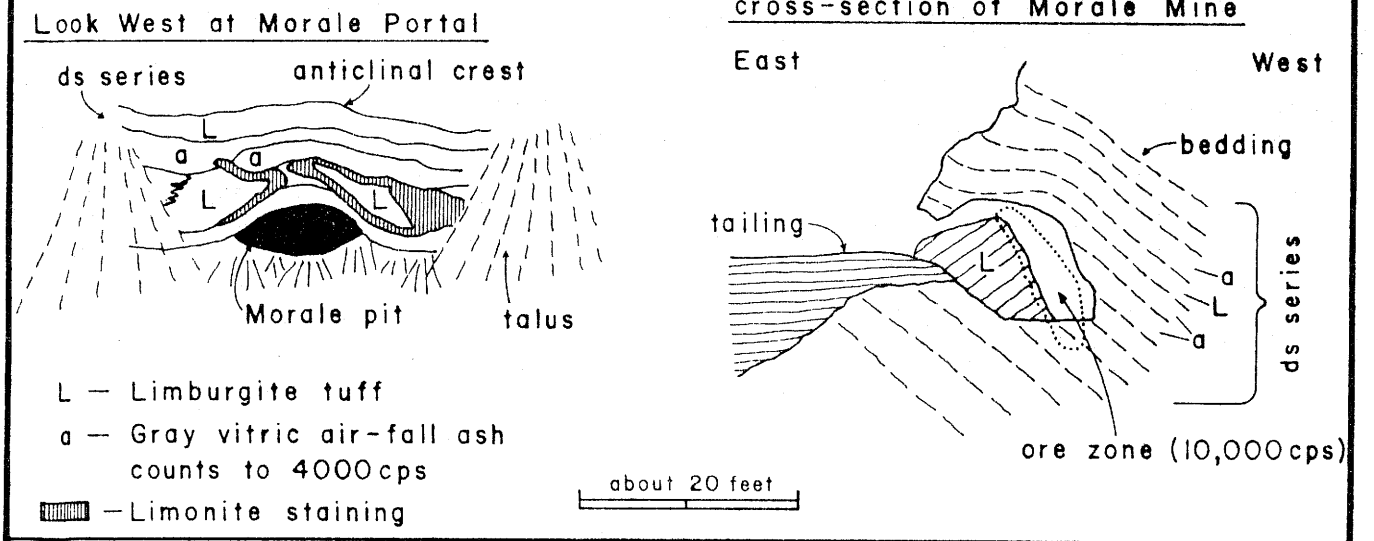
In detail, uranium is noted in two positions within the diatreme sediments. Both positions are noted at the Seth-la-kai diatreme, containing the Morale claim (see Figure 26). Uranium is stratigraphically confined to sandstone, mudstone, or limestone beds in the main mass of the sediments. And, at the Morale claim proper (Figure 26), uranium is concentrated (with assays to 0.50% U_3O_8) in lowermost permeable volcanic sandstone beds which are draped over blocks of limburgite tuff which protrude through the unconformity between the lower volcanic slump debris and the overlying diatreme sediments. Here, and elsewhere, there is a clear concentration of radioactivity near anticlinal crests in the younger sediments. Some radioactivity has been noted along fault boundaries at or near the diatreme margin, as well.

The recent USGS-BIA Hopi Buttes drilling program consisted of 24 holes through the diatreme sediment beds at Seth-la-kai diatreme and 6 holes drilled into Hoskie Tso diatreme. Based on this drilling, the USGS projects a content of nearly 400,000 lbs of U_3O_8 in an upper 50 foot interval at Seth-la-kai. Previous production from the Morale ore zone is listed as 576 lbs of U_3O_8 in grades of 0.15% U_3O_8 and 0.04% V_2O_5 between 1954 and 1959. Hoskie Tso diatreme drilling indicated very low uranium grades and thicknesses. Overall, however, assuming 30 diatremes to have similar uranium contents and ore volumes as Seth-la-kai, the USGS projects a content of 30,000,000 lbs of U_3O_8 in the Hopi Buttes, assuming average grades of 0.01% U_3O_8.





from ABG field work



Geology of Morale Mine, Hopi Buttes, Navajo County

Figure 26

OTHER HOST ROCKS

Other Paleozoic and Mesozoic sedimentary rocks of the Colorado Plateau region are known to contain uranium anomalies. These strata include, in order of decreasing age, Naco-Supai Formations, basal Coconino Sandstone, the Kaibab Limestone, basal Moenkopi Formation, the Sonsela Sandstone of the Chinle Formation, the lower Kayenta Formation, and the Dakota Sandstone.

Radioactive clastic units near the contact of the Naco and Supai Formations, near the Pennsylvanian-Permian boundary, at Promontory Butte, Gila County have been explored by at least two drill programs in the 1970's. One shipment of less than 500 tons of low grade ore was made from the Neptune (Promontory Butte listing) in 1979. The host rocks consist of gray sandy shales associated with limestone pebble conglomerate lenses, both overlain and underlain by sandy redbeds (see Blazey, 1971; Peirce and others, 1977). The strata contain locally abundant carbonized plant remains. Uranium and copper carbonate mineralization are apparently loosely associated with the gray shales, contacts between various beds, and organic matter.

One occurrence of radioactive oxidized copper carbonates and iron-manganese staining is recorded at Saucer No. 1 claim, Coconino County, at the contact between the Hermit Shale and the Coconino Sandstone.

Radioactive oxidized copper occurrences in the Permian Kaibab Limestone are recorded at the following localities: In Coconino County at the Airport mine, Anita copper mine, Barranca de Cobre, Blue Bonnet, Copper No. 1, Packrat, National, Twin Tanks, and unnamed "B" occurrences, and at the School section claims of Mohave County. The Copper No. 1 claims shipped 29 tons of ore @ 0.10% U_3O_8 and 0.02% V_2O_5 in late 1956 under the name of the Doty Group.

The Kaibab occurrences are usually copper carbonates lining fractures, sometimes localized at crests of small tight folds. In the Willaha-Anita area north of Williams, some drilling was done in the early 1970s and again in 1979-1980 by at least three companies. The contemplation of a possible relationship between these surface copper-uranium shows and a possible buried pipe structure as represented by the nearby Orphan Lode, a major copper-uranium producer, is probably sparking this interest. Preliminary indications from the Willaha-Anita area are that pipe structures are present. If so, then this indicates that elements of pipe formation transgress upwards at least to the Kaibab Limestone, an observation not discernable at the Orphan Lode or at Hack Canyon because the pipes there top-out below the Kaibab.

Four radioactive occurrences with copper shows are recorded from the basal Moenkopi Formation: in Coconino County at the Clover Leaf mine No. 1 and at unnamed "C"; and in Mohave County at the Fredonia No. 1 and Little Three No. 1 claims.

Mineralization near the Sonsela Sandstone of the Petrified Forest Member of the Chinle Formation is found at the Mac No. 3 claims and the Ruth Mine of Navajo County. Stratigraphically, these grade downward into the numerous lower Petrified Forest Member ores around the Cameron-Holbrook district. The Ruth mine was the largest of the Holbrook area producers and is credited with small shipments in 1976 and 1978.

The lower Kayenta Formation yielded some uranium ore from the Cameron area (Coconino County) from two properties, Ward Terrace and Yellow Jeep during the 1950s.

The Navajo Sandstone (Jurassic? or Triassic?) contains three uranium-copper occurrences, in Coconino County at the Copper Mine Trading Post and at White Mesa copper claims, and in Apache County at the Bluestone No. 1 claims. Bluestone produced 53 tons of ore @ 0.22% U_3O_8 in 1956.

The Recapture Member of the Morrison Formation in the Lukachukai Mountains contains several anomalies which are noted in Chenoweth and Malan (1975). These are not plotted on the Lukachukai district map because of lack of location details.

Finally, the Cretaceous Dakota Sandstone contains one radioactive anomaly in Navajo County at the Fred Zahne Nos. 1-5 claims in a uraniferous lignitic coal bed.

COLORADO PLATEAU MINERALIZATION

SYNTHESIS

Many aspects of uranium mineralization in Colorado Plateau sedimentary rocks reccur in most host lithologies, irrespective of age. These have been noted by many previous workers including Finch, 1953; Stokes, 1954; Mullens and Freeman, 1957, Kerr, 1958; Peterson, 1977; and Galloway, 1979. The important themes are repeated here:

a) A primary lithologic characteristic of host rocks is interbedded sandstones and mudstones rather than sandstone-dominated units. The Lukachukai district map (Plate 19) shows this relationship very well. Auxiliary feldspar and mica grains are frequently mentioned.

b) Carbonized plant debris, present as mattes between sandstone-mudstone beds or disseminated in sandstones, or as fossil wood or log fragments, is ubiquitous in larger uranium deposits.

c) The recurring paleonenvironmental theme involves fluvial (stream) systems on alluvial fans, or delta distributary channel systems adjacent to lacustrine environments. No major Arizona Plateau sedimentary deposit is contained in any other paleonenvironmental setting.

d) Plateau uranium deposits are geochemically segregated - for unknown reasons - into either uranium-copper or uranium-vanadium associations (Finch,1953).

e) Plateau-type structural features are often noted to "accompany" uranium districts and mention is made of genetic relationships (Kerr, 1958; Stokes, 1954), the hypothesis being that the structures recognized today (monoclines, uplifts, etc.) had some movement history during sedimentation and hence somehow controlled favorable lithologies such as meander bend positions. At times, though, as in the Lukachukai Mountains, these effects may be very subtle, or even nonexistent. Overall, this aspect of the theme of Colorado Plateau uranium distribution may relate to the simple uncovering and erosion of the strata along flanks of uplifts or monocline middle limbs, making the mineralized strata discoverable.

f) The geochemically divergent mineral associations for the Plateau uranium deposits indicates complex, multiphase migration, chemical zonation, and fixing of uranium and related species (see Botinelly and Weeks, 1957). Paleothermometry measurements (Coleman, 1957) indicate low (55-115^{o}C) temperature of mineralization. Bleached zones, liesegang banding, fracture control of some veins, and mineral zoning all indicate post-sedimentation, diagenetic movement of ore-related solutions at somewhat elevated temperatures. Radiometric dating of uranium minerals and authigenic clays suggest a Jurassic-Cretaceous age for mineralization, a result that agrees with field data.

g) The ultimate source of uranium is most probably the Mesozoic arc volcanism and plutonism along the west coast of North America. Malan (1968) suggests that the pyroclastic components of this volcanism could be a primary source of Colorado Plateau uranium. Deep-seated hydrothermal emplacement of the ore-bearing solutions has sparce supportive evidence for the Plateau deposits (see Finnell, 1957 and Kerr, 1958). An alternate source of uranium

could be Precambrian crystalline rocks present either in the Mogollon highlands or beneath the Colorado Plateau. Silver (1976) and Silver and others (1980) suggest the presence of a regional uranium anomaly in Precambrian basement rocks centered beneath the part of the Colorado Plateau that contains all the major producing uranium districts. Their work is based on uranium concentrations in igneous zircons.

SOUTHERN ARIZONA REGION

STRATABOUND OCCURRENCES

Dripping Spring Quartzite

During 1953-1960, a total of over 122,000 lbs of U_3O_8 concentrate has been produced from 18 mines in the Precambrian Dripping Spring Quartzite in Gila County, with an overall average grade of nearly 0.20% U_3O_8. The vanadium content of the ores from two properties amounted to 6500 lbs of V_2O_5.

Uranium was discovered in the Dripping Spring Quartzite in 1950 at the Red Bluff property and in 1953 along Workman Creek. In the spring of 1954 the AEC conducted a three-month low-level airborne gamma ray survey of the Sierra Ancha area, resulting in more than twenty new discoveries which were subsequently prospected. In July, 1955, an AEC ore-buying station was established at a railhead at Cutter (near Globe) primarily to purchase Sierra Ancha Dripping Spring Quartzite ores. It closed June 30, 1957, when the AEC determined that remaining ore volumes were too small for further economic consideration. Because this buying station also received other ores from southern Arizona, its operation essentially controlled uranium mining in the region.

Overall, uranium production in Dripping Spring Quartzite ores has been disappointing. Cutoff width of ore grade veins has often been one to two feet. Past that width, dilution of ore by low grade wall rock was a serious problem, especially since ore sorting was difficult by using geiger counters. Ore veins were quite limited in extent, typically measuring 2 ft thick, 10 to 20 ft in height, and 100 to 200 feet in length.

Major discussions of Dripping Spring Quartzite uranium occurrences are found in Williams (1957), Schwartz (1957), Walker and Osterwald (1963), and Granger and Raup 1969(a) and 1969(b). In addition, the NURE Mesa quadrangle evaluation report prepared by Bendix, in review as of February 1981 contains an appraisal of Dripping Spring Quartzite occurrences. See Granger and Raup (1964) and Shride (1967) for discussions of central Arizona younger Precambrian stratigraphy.

The Dripping Spring Quartzite is a member of the late Proterozoic-aged Apache Group, which consists in ascending order of the Pioneer Shale, the Dripping Spring Quartzite, the Mescal Limestone, and a capping basalt (Figure 27). The Apache Group sediments were deposited on a surface cut on Precambrian granites and metamorphic rocks that have age dates as young as about 1,380 m.y. The Apache Group is overlain disconformably by the Troy Quartzie. All of these sediments are intruded by massive diabase-syenite sills that have age dates ranging from 1,050 to 1,250 m.y. (all age data from Livingston, 1969). Apache Group rocks are approximate lithologic equivalents of the Unkar Group sediments of the Arizona Grand Canyon region (described by Breed and Roat, 1974), and are rough age equivalents of the middle Belt Carbonate unit of the Belt Group sediments of Idaho, Montana, Alberta, and British Columbia, as described by Harrison (1972). Curiously, as Harrison points out, anomalously high copper values

are found in many of the Belt terrain rocks, and are attributed to a syngenetic-diagenetic origin. Similarly, farther north in northern Saskatchewan, a moderate-size uranium deposit in quartzites of the Athabasca Formation (± 1,250 m.y. age) at McClean Lake is now being developed (anonymous, 1980). Here it is suggested that the uranium was hydrothermally derived from the underlying basement complex and precipitated in a reducing environment in the sandstones before their metamorphism to quartzites.

Carlisle and others (1980) describe uranium anomalies in the lower part of the Kingston Peak Formation of the late Proterozoic Pahrump Groups of southern California. These sediments, like the Apache Group, rest on 1400 m.y. crystalline rocks containing abundant uranium anomalies (World Beater complex). The Kingston Peak Formation is overlain unconformably by the Noonday Dolomite. Carlisle, et al, suggest derivation of uranium in the sediments from the eroding "islands" of older crystalline rocks during Pahrump time. Both quartz pebble conglomerates (Witwatersrand model) and pelitic schists containing unusual amounts of pyrite, chalcopyrite, and graphite are anomalously radioactive. It cannot be dismissed at this writing that the Pahrump and Apache Groups were part of the same sedimentary cycle, and as such may share information on origin of late Proterozoic stratabound uranium in the Western United States (see Carlisle and others, p.41-42 and 45). Studies reviewed in the Carlisle reference, based upon microfloras,and geologic relationships to diabase masses of presumed age indicate a possible pre 1.1 b.y. age for part, or all of the Pahrump Group.

Dickinson's (1977) Figure 1 shows the extent of known occurrences of sediments of this general age in North America. See also a general paper on the probable plate tectonic setting of the Apache Group rocks by Sears and Price (1978). Figure 28A from Shride (1967) is a north-south cross section through the Sierra Ancha, and suggests a pre-Troy warping and beveling event, and Figure 28B shows a post-Troy, pre-Devonian Martin block faulting event probably associated with the Antler Orogeny of Nevada. This is, in essence, the structural setting of the Apache Group rocks seen today in the Sierra Ancha, simplified as Figure 29. Figure 30, also from Shride (1967), shows all the known outcrops in Arizona of Apache Group rocks and the associated diabase. Outside of this region in Arizona the Apache Group rocks were apparently either not deposited or removed by erosional events ranging in age from late Precambrian to mid-Cenozoic. It is thought from drillhole information that the Apache Group rocks do not extend far to the north or east from the Sierra Ancha under the Colorado Plateau Paleozoic blanket. (H. Peirce, pers. comm., 1980). The Apache Group is not continuous with the Grand Canyon Unkar Group rocks under the Paleozoic cover of the Coconino Plateau because of either nondeposition on the Transcontinental Arch or extensive pre-Paleozoic erosion along this same feature, or both. Figure 29 suggests the southwest and northeast limits of the Apache Group rocks in the Sierra Ancha are, respectively, erosional removal in the Tonto Basin area and the burial of the section under Paleozoic cover east of the Canyon Creek fault.

Minor oxidized copper minerals occur at many of the deposits, though not in mineable quantities. See Granger and Raup (1969a, p.80) for a table listing ore and accessory mineral occurrences. Purple fluorite has been recognized only at the Hope 3, Sorrel Horse, Big Buck, and Tomato Juice deposits, and only in small amounts. The fluorite coexists with pyrite in thin veinlets in the central part of the radioactive vein zones.

Two theories exist to explain the origin of the uranium. Schwartz (1957) and Granger and Raup (1969a) favor the explusion of uranium-copper fluids from diabase differentiates and their subsequent incorporation into the favorable quartzite horizons along fracture channelways that formed adjacent to intrusive masses. They suggest that unidentified structural, mineralogical, or chemical properties of the gray unit made it very favorable as a receipient of the uranium mineralization (p.97). They note, however, that these sediments contain abnormally high carbon, and that iron sulfide contents could have contributed to a H_2S gas partial pressure that could have reduced mobile uranium species to UO_2. Granger and Raup (1969a, p.102) also note that at three deposits (Hope 1, Workman 1, and Red Bluff) uraniferous veins appear to end abruptly at contacts with diabase dikes and sills, as though the diabase had cut the mineralized veins.

Williams (1957) suggests, on the other hand, that the diabase, even with its alkalic differentiates, had less than one tenth the amount of uranium as the gray unit of the Dripping Spring Quartzite originally, and thus the latter is the more probable original source of the uranium. He subscribes, however, to the hydrothermal movement of the uranium into the fractures at the time of the diabase intrusions.

Granger and Raup (1969a, p. 76) list a series of uranium-lead age dates for five Dripping Spring uraninites. A series of single uranium-lead pair model ages range mostly from 900 to 1,300 m.y. with only four out of 15 determinations recording less than 900 m.y. In addition, one lead-lead determination on cognetic galena gave an age of 1,140 m.y. Concordia plots of the two isotopic systems produced two sets of curves which intersected at about 1,050 m.y. These numbers may minimally approximate the age of ore formation in view of the fact that on the whole, the dated Dripping Spring uranium minerals are in good radiometric equilibrium (Granger and Raup, (1969a, Figure 43). These ages are consistent with all known age relations of the Apache Group, and indicate that the mineralization is either syngenetic with Apache Group sedimentation or not appreciably younger than the diabase intrusion.

It is this author's opinion that Williams' (1957) suggestion is the more reasonable one, since a) other similar-appearing Dripping Spring Quartzite units are barren of mineralization, and b) the upper member nearly ubiquitously contains anomalous radioactivity in several mountain ranges, whether or not diabase intrusions are nearby. Shride's cross-section (Figure 28A) shows a gentle Apache Group-Troy Quartzite angular unconformity, a hiatus which could serve as a time during which mineralization could have occurred (H.W. Peirce, pers.comm.,1981).

Pyrometasomatic hematite-specularite mineralization bedded into the Mescal Limestone along Canyon Creek was earlier thought to relate genetically to the diabase intrusion. More recent suggestions by Moore (1968, p.27-29) discount this hypothesis.

Example - Red Bluff Mine

The Red Bluff claims, discovered in 1950, record the first uranium find in the Dripping Spring Quartzite. The deposit, seen in Figure 31, contains many characteristics of Dripping Spring occurrences. The mined deposits are in two main separate stratigraphic zones in a gently eastward dipping Dripping Spring Quartzite section on opposite sides of N20°E-trending Warm Creek Canyon, in the southern-most Sierra Ancha. Warm Creek follows a 150 foot-thick diabase dike that has intruded a fault zone with about 250 feet of apparent reverse, east side down movement. Mining has followed three separate stratigraphic zones, above and below the "barren quartzite" as seen in the cross section, and has also exploited a series of strong N70°W mineralized and limonite-filled fractures which strike at right angles to the large diabase dike. Within two miles to the southeast, as seen on the map, a series of large-scale shear zones with possible left-lateral offset also trend N70°W, but lack known mineralization.

Primary minerals at the deposit include uraninite, pyrite chalcopyrite, and galena, all disseminated in the quartzite host and often concentrated along bedding planes. Oxidation near the present land surface in recent times has produced metatorbernite, bassetite, uranocircite, and uraniferous hyalite as fracture coatings. These minerals also line bedding planes and are disseminated in leached, weathered host rock. Much of the Red Bluff uranium ore shows indications of recent uranium leaching, and has chemical uranium content that is 10-60% low when compared to radiometric uranium content (Kaiser, 1951, Table 1). As well, Granger and Raup (1969a, Table 5), indicate lower U-Pb age dates at Red Bluff than any of the other Dripping Spring localities. All these effects are probably related to the rapid modern weathering of the hilltops by the southward flowing streams in the area around the Red Bluff Mine.

Exploration at Red Bluff is continuing. Drilling and eastward extension of an adit in the eastern mine block by Wyoming Mineral Corporation (Exploration arm of Westinghouse Corporation) in the past several years has outlined 2.5 million pounds of low grade uranium ore that has undergone some metallurgical testing (Paydirt, Feb.1977 issue, p.64). Wyoming Minerals Corporation is also drilling as of late 1980 in the Workman Creek area.

Since 1977, Dripping Spring ores from the old Lucky Boy property of the Southern Pinal Mountains have been mined and heap leached by Pinal Minerals Corporation. Several shipments of a brine concentrate have been made from the mine.

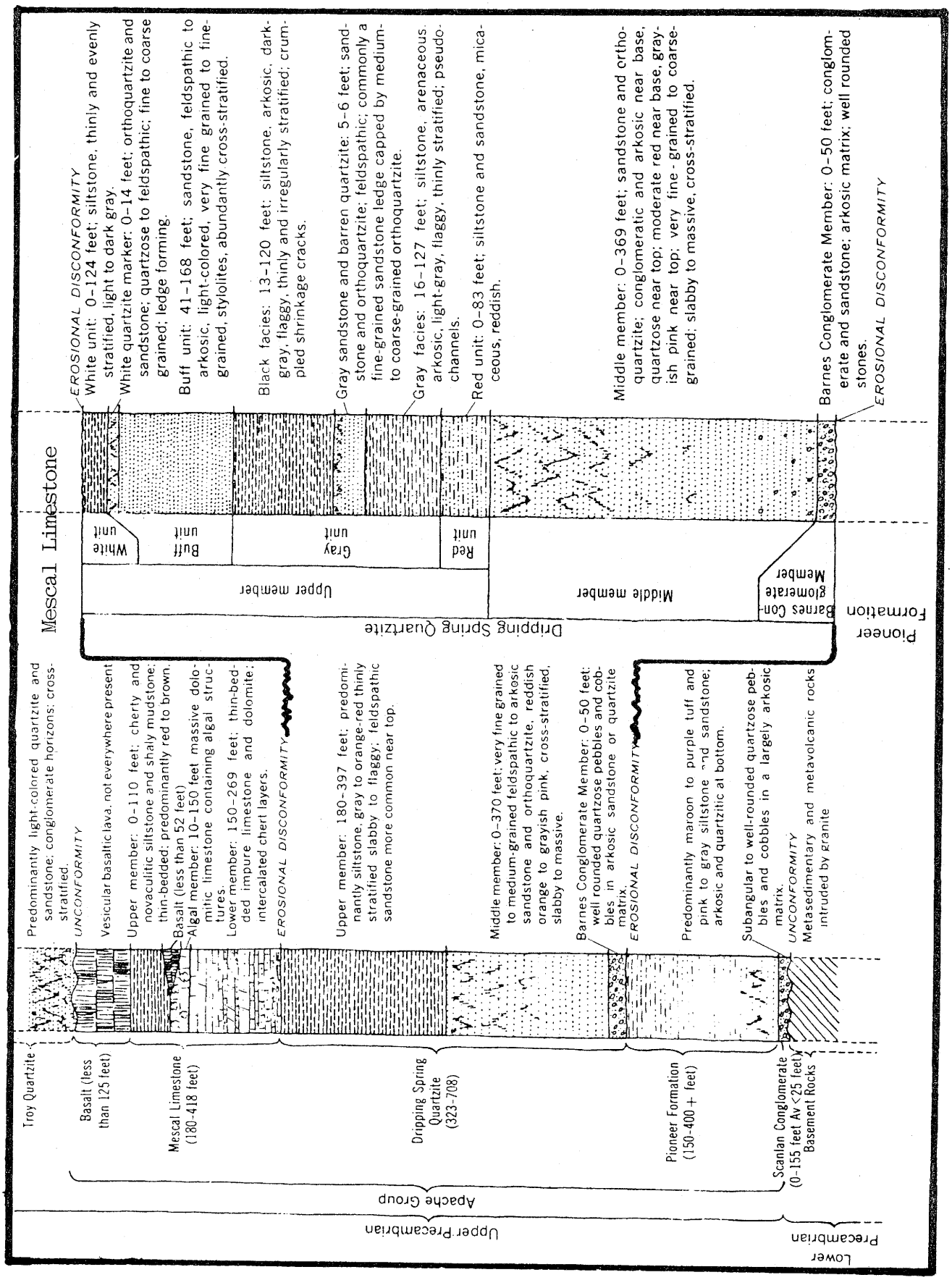


Figure 27 . Apache Group-Dripping Spring Quartzite stratigraphic column, from Granger and Raup (1964).

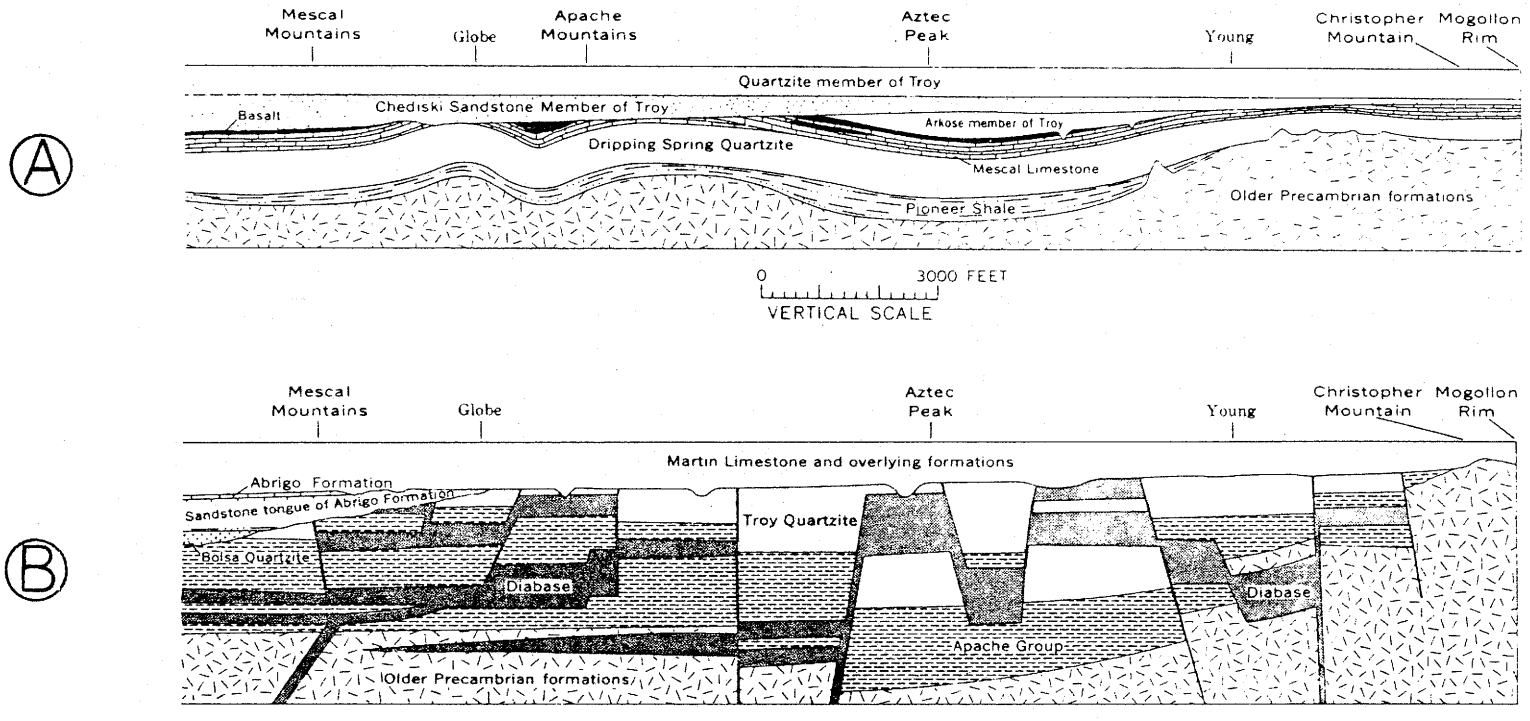


Figure 28

North-south cross sections through the Sierra Ancha, Gila county, from Shride (1967).

(A) at the end of Troy Quartzite time

(B) at the end of Martin Fm. time

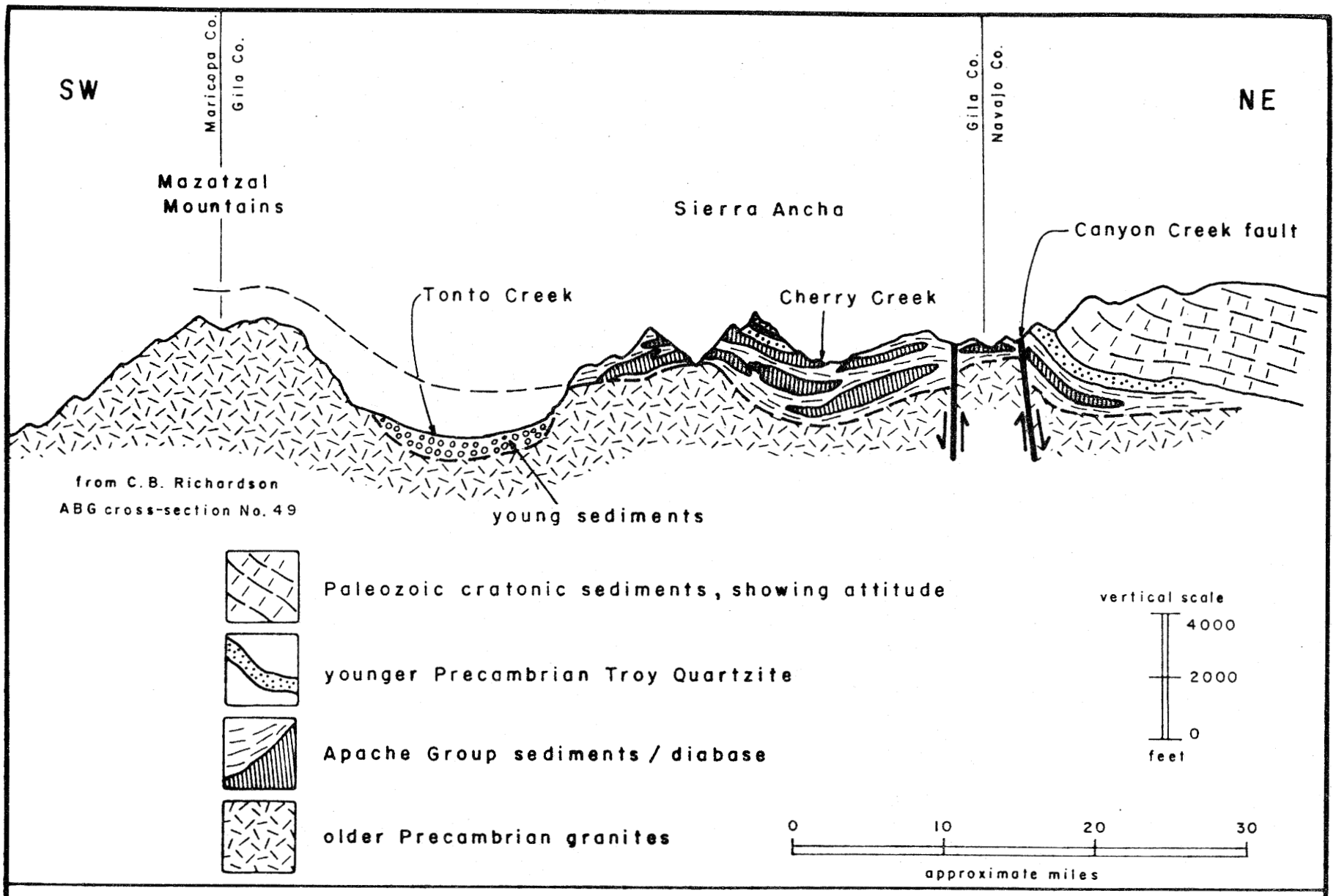
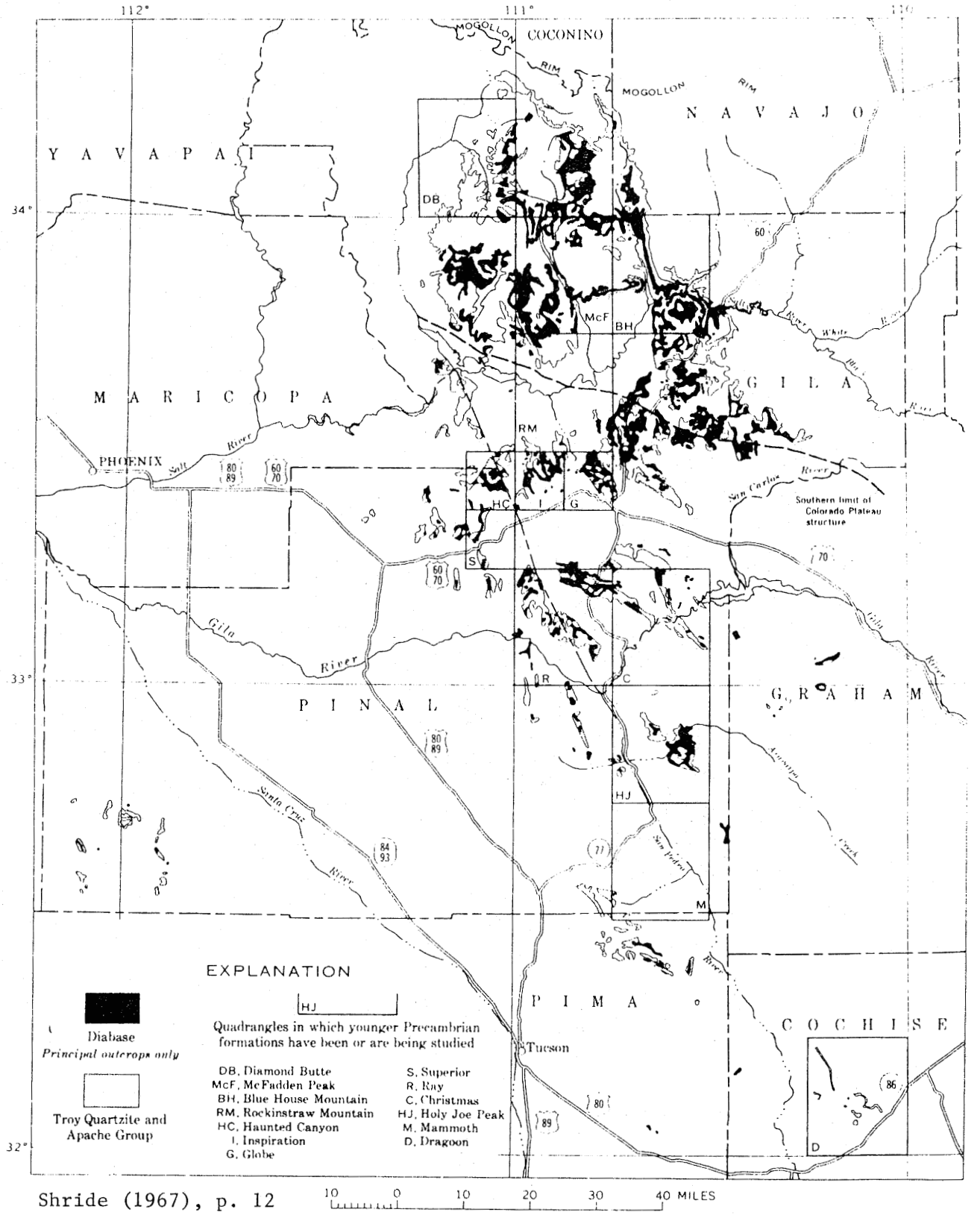


Figure 29

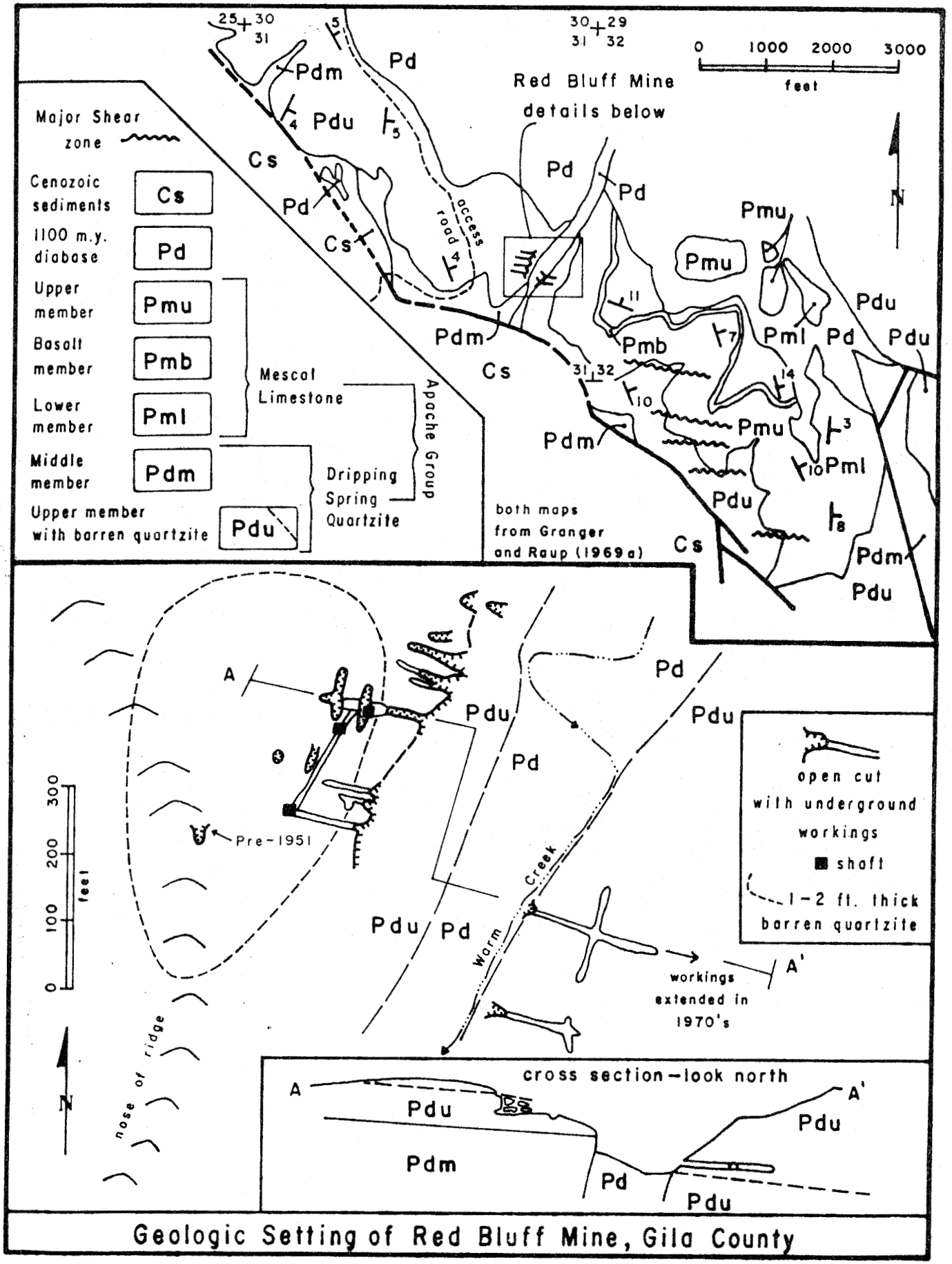
Generalized SW-NE Cross-Section showing extent of Apache Group Outcrops, Sierra Ancha, Gila County



Shride (1967), p. 12

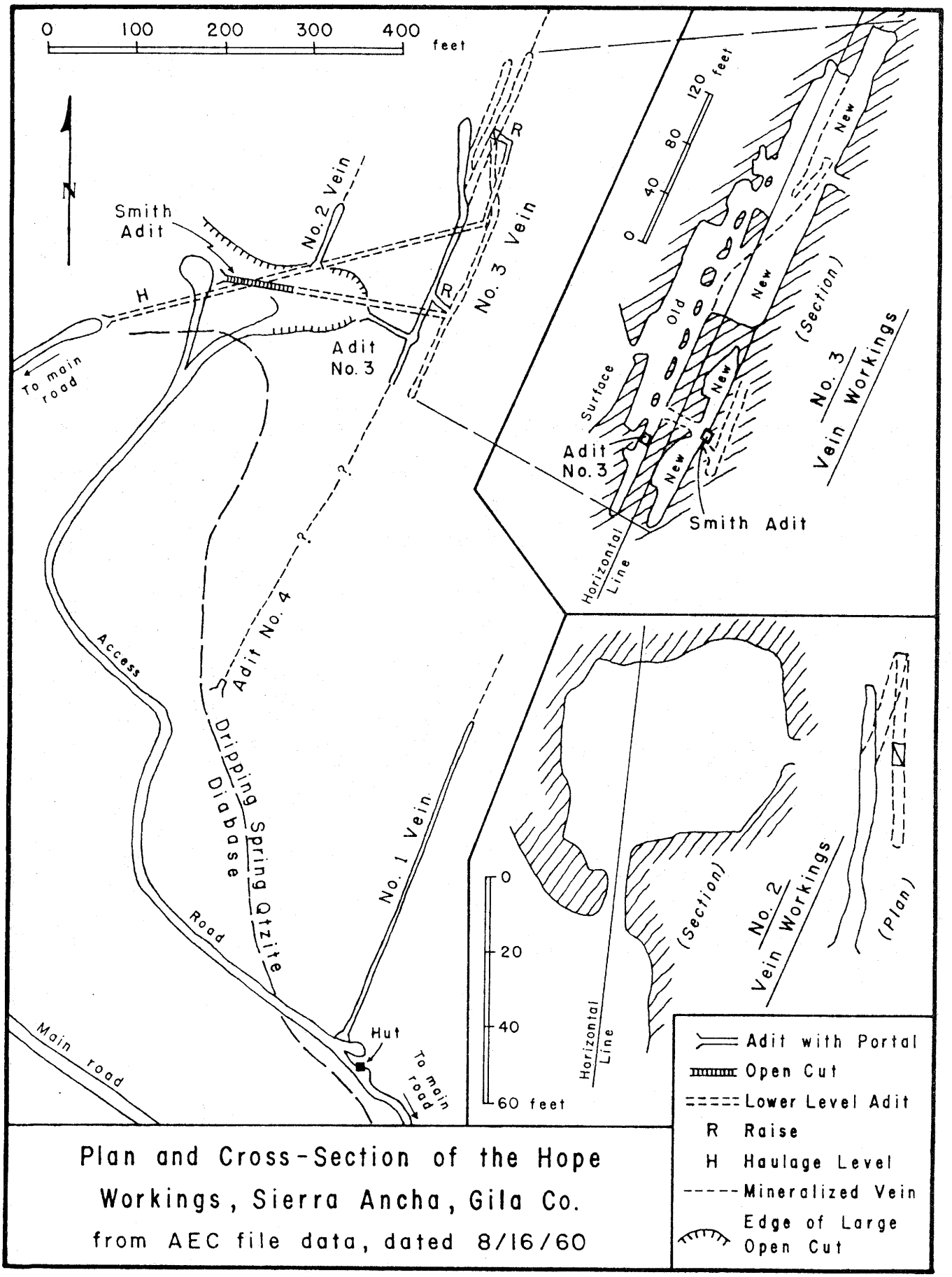
Outcrops of younger Precambrian strata and coextensive diabase intrusions in southeastern Arizona. Modified from county geologic maps published by Arizona Bureau of Mines, 1958–60.

Figure 30



Geologic Setting of Red Bluff Mine, Gila County

Figure 31



Plan and Cross-Section of the Hope Workings, Sierra Ancha, Gila Co.
from AEC file data, dated 8/16/60

Figure 32

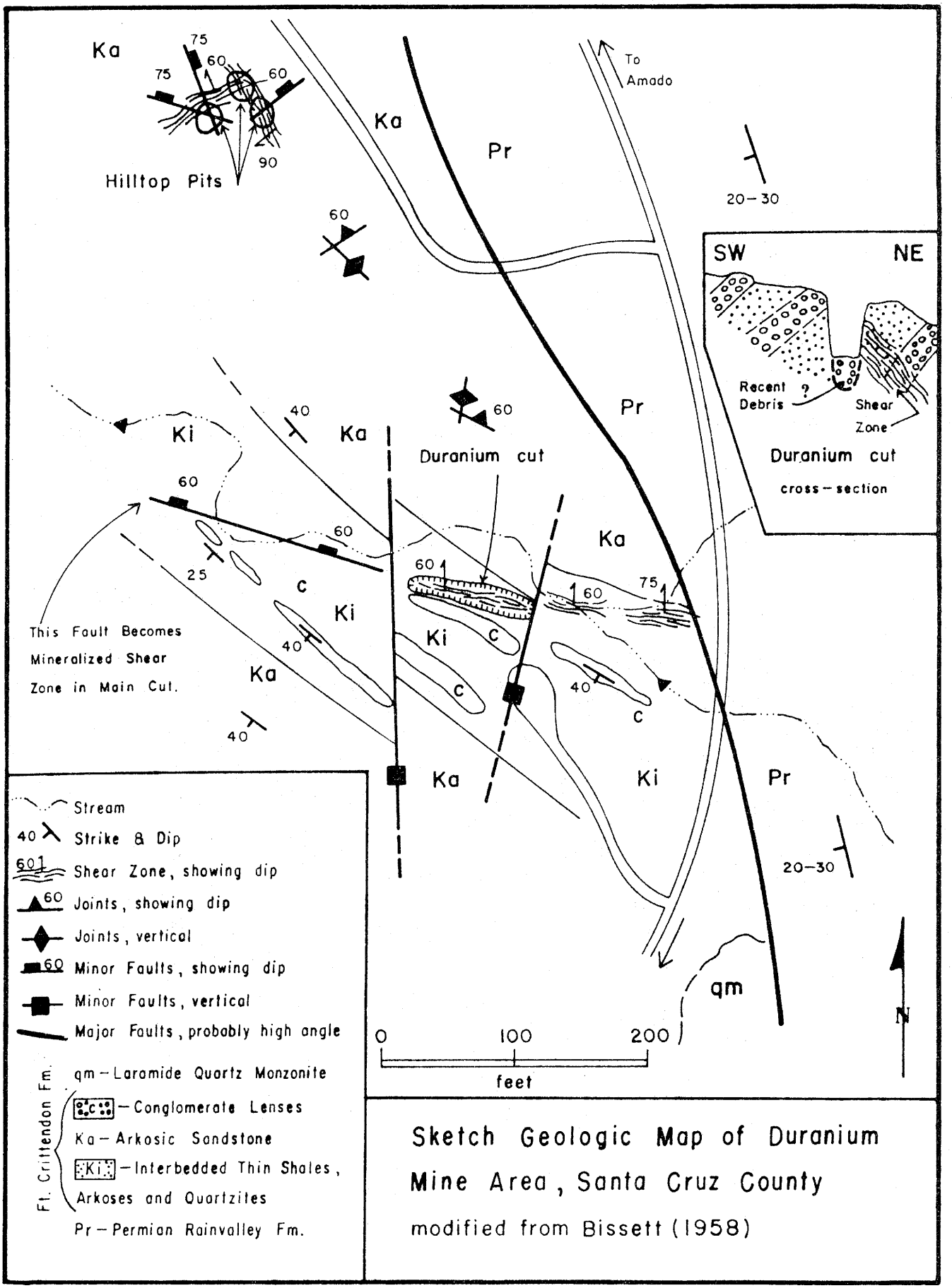
Cretaceous Sandstones

In contrast to the relatively abundant Mesozoic uraniferous sandstone deposits of the Colorado Plateau, southern Arizona has a paucity of such occurrences. Only three are noted: The Dipsy Doodle claims of Cochise County; the Duranium Mine of Santa Cruz County, and "unnamed D" occurrence of Pima County.

At the Dipsy Doodle claims east of Douglas in the Perilla Mountains, radioactivity is associated with limonite-hematite alteration zones in shales and sandstones of the Bisbee Group rocks of Lower Cretaceous age. At "unnamed D" occurrence on the southwest flank of the Whetstone Mountains, stratabound chrysocolla with very slight radioactivity fills intergranular voids in a 2-4 foot thick sandstone unit in a thick southward dipping clastic sequence mapped as Bisbee Group by Drewes (1980).

The only known uranium production from Mesozoic clastic rocks in southern Arizona comes from the Duranium Mine on the northwest flank of the Santa Rita Mountains. See Figure 33 for a sketch geologic map of the area. Drewes (1971, Mt. Wrightson quad geologic map I-614) maps the host rock as the upper red conglomerate and tuff member of the Upper Cretaceous Fort Crittenden Formation, and shows the Cretaceous clastics here as in high angle fault contact to the south and east with Paleozoic limestones. The entire Cretaceous section lies beneath a late Cenozoic pediment surface that terminates at the resistant Paleozoic outcrops. Uranium mineralization follows a N80°W shear zone that cuts across bedding in a conglomerate-arkosic sandstone-red shale bedded sequence which dips about 35°SW. Intense hematite and minor malachite follow the shear zone as well. Two miles to the southeast, a series of WNW-trending quartz latite dikes (dated at 67 m.y. by K/Ar) are mapped by Drewes (1971). These may relate to the Duranium shear zone insofar as their strike directions coincide.

The most radioactive rock at Duranium is a very hard, dense arkosic sandstone with void spaces filled with a shiny black mineral. 680 tons of ore @ 0.20% U_3O_8 was produced in 1956-57 from a long, narrow 15 ft deep dozer pit oriented along the shear zone. Mining stopped when the AEC ore buying station at Cutter (Globe) closed. Indications are that more ore-grade material remains in the area. Radioactivity and minor prospect pits are found on several knobs containing the same strata up to 0.5 miles northwest of the main pit, approximately along strike of the units exposed in the pit. Hence, there are indications of an underlying stratigraphic control of mineralization in the area, rather than an exclusive structural control.



Sketch Geologic Map of Duranium Mine Area, Santa Cruz County

modified from Bissett (1958)

Figure 33

Cenozoic Sediments

The Basin and Range portion of Arizona contains many stratigraphically confined uranium anomalies in fine-grained fluvial, paludal, and lacustrine rocks, of Cenozoic age, among them being the publicized Anderson Mine in the Date Creek Basin. This area contains estimated reserves of at least 30 million pounds of U_3O_8. In Arizona, some of these sedimentary occurrences are described in detail by Scarborough and Wilt (1979). Interesting analogs in California are discussed by Leedom and Kiloh (1978) and a report by Lucius Pitkin, Inc. (1980), and in Texas and Chihuahua, by Galloway and Kaiser (1980). Preliminary work on calcrete-gypcrete uranium deposits in the Southwest are compiled in Carlisle (1978).

Southern Arizona uranium occurrences of this category are found in sediments of Oligocene, Miocene, and Pliocene ages. Many of these rocks are coeval with a variety of volcanic rocks which commonly range in composition from high-potassic andesites through rhyolites, and occasional "ultra-potassic" trachytes (Shafiquallah, et al, 1976), yet, the fine-grained sediments contain many more radioactive anomalies than do the volcanics. In general, these deposits are assumed to have formed in paleo basins of restricted depth and lateral extent. Some of the larger basins were undoubtedly tectonically created, while many of the thinner sedimentary deposits found in volcanic terrains probably were created by volcanic damming effects as volcanism proceeded.

Lithologies in southern Arizona favorable for uranium mineralization include fetid, thin-bedded limestones that often contain chert pods or stringers; shale-mudstone lithologies with white, gray, or yellow-green colors; white marlstones (intimate mixtures of clays and finely divided calcium carbonate), thin-bedded aphanitic dolomites that sometimes contain plant root casts filled with chert; and dark gray-to-black carbonaceous mudstones or sublignites. In the absence of structural control, coarser-grained lithologies such as sandstones or conglomerates do not contain anomalies, nor do redbed lithologies. Examples of anomalies in redbeds with structural control are at the Cottonwood claim and Horseshoe Dam (Maricopa County), and the Rayvern and Ten Dee's claims (Yuma County).

Table 1, below, lists typical lithologies in southern Arizona which have radiometric or uranium shows, along with examples illustrating the lithologies:

TABLE 1. Examples of Uranium Occurrences in Cenozoic Sediments

Radioactive Lithology	Example(s)
Limestone, sometimes fetid, sometimes cherty	Masterson Claims, Mohave Co. Cave Creek Area, Maricopa Co. Dutchess Claim, Pima Co. Center Chance Claims, Pima Co. Catherine and Michael, Mohave Co.
Aphanitic dolomite, light colored	Los Cuatros Claim, Maricopa Co.
Light-colored mudstone	Teran Basin, Cochise Co. North Chance Claim, Pima Co. Muggins Mtns. Area, Yuma Co. Dab; Wharton; Sunset; Mohave Co.
White massive marlstones	Xmas; Half Moon Claims, Pima Co. Cottonwood Area, Verde Valley, Yavapai Co.
Dark carbonaceous mudstones to sublignites	Giger Claims, Gila Co. Anderson Mine, Yavapai Co.

Stratigraphic sections containing Oligocene-Miocene layered rocks are often found tilted in a rather uniform direction and amount over large regions within the Basin and Range country of the Cordillera. Stewart (1980) suggests a certain elongate regionality to these "domains" of tilted rocks, though the ultimate reason for their existance is unknown at this time. Many of the Southern Arizona uranium occurrences in Oligocene-Miocene strata or fault zones are in terrains affected by this phenomenon. Examples include many of the occurrences in the Muggins Mountains, and the Rayvern claims, Plomosa Mountains of Yuma County, the Anderson Mine area of Yavapai County, the Horseshoe Dam sites of Maricopa County, Catherine and Michaels claim in Mohave County, and the Chance Group claims of Pima County with related Teran Basin deposits of Cochise County, to mention a few. Evidence is gathering that some of this tilting is due to NW-SE directed curviplanar fault systems ("listric" faults) which cause antithetic rotation of upper plate rocks (those above a master basal flat fault of unknown extent) to produce dips toward the listric fault, as faulting proceeds. The result, well displayed in the cross section near the Anderson Mine (Figure 36), is that the same stratigraphic section may be repeated time and time again at the surface, and hence, the observed tilted section appears much thicker than it really is.

The following examples are uranium occurrences in Cenozoic sedimentary rocks in Southern Arizona of three different ages. It is suggested in Scarborough and Wilt (1979) that there appears to be a certain regionality to the ages of Cenozoic sedimentary uranium occurrences in Southern Arizona, based upon the proposition that only at certain times were there fluvial-lacustrine environments of any extent that favored uranium deposition. These times, from which the examples were drawn, were during the late Miocene-Pliocene (6-2 million years B.P.), during the middle of the first half of the Miocene (20-15 m.y.), and during the middle part of the Oligocene (30-25 m.y.).

In all three periods there were regions where fluvial, deltaic and lacustrine facies were in close proximity, and where numerous uranium occurrences are now recorded. The examples are given in order of increasing age, in parallel with the age listings above. The Anderson Mine strata are rough age equivalents of the radioactive dolomites around New River and Cave Creek (Los Cuatros locality).

EXAMPLES:

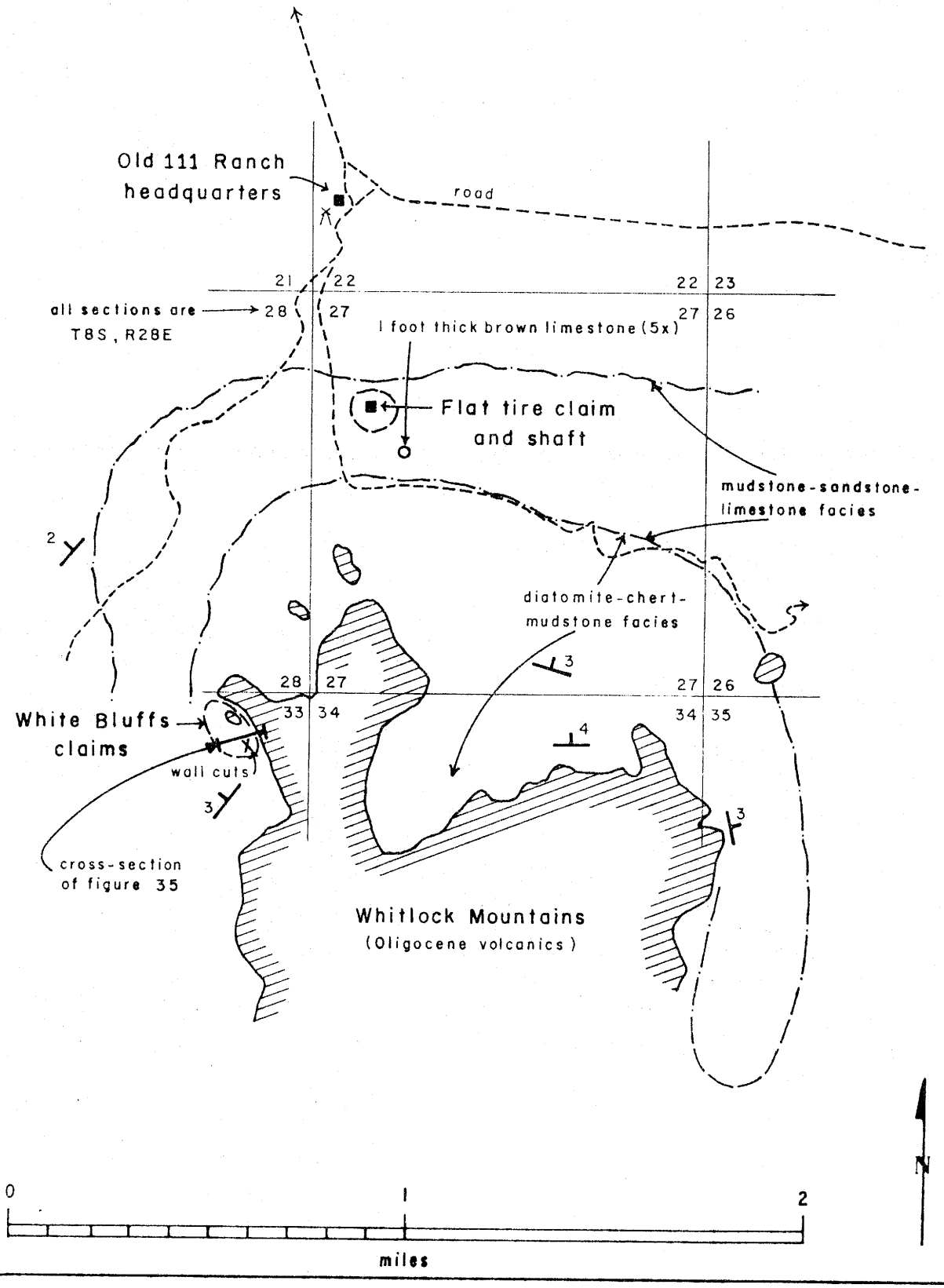
Pliocene Rocks near Safford, Graham County

Figure 34 is a general map view of the northern Whitlock Hills, about 17 miles southeast of Safford, in Graham County. In this area a section of quiet water, lacustrine and paludal fine-grained sediments of Pliocene age has been deposited against a mass of Oligocene volcanics. Figure 35 (top) is a generalized south-looking cross section showing general lithologies and radioactive beds at the White Bluffs claims. The anomalous zones are in (a) the cherts of a mixed tabular green chert and gray-green mudstone zone, and (b) the basal 2 feet of an overlying 20 ft thick diatomite zone. Nearby

masses of green chert incorporated into the diatomite are not anomalous. Figure 35 (bottom) is a nearby south-looking view of the same stratigraphy, folded nearly isoclinally, and displaying the highest radioactive readings at the crests of anticlines (see the Morale claim, Hopi Buttes, Navajo County for an interesting analog). Other claims in this area are staked on similar lithologies. At the Flat Tire claims (Figure 34) diatomaceous mudstones and a nearby thin, brown, fetid limestone containing bivalve fossil forms are anomalous. Most mudstones and cherts that have been analyzed for organic carbon in the White Bluffs-Flat Tire area contained 0.08-0.30% C (NURE data).

The exposed Pliocene section in the area measures about 100-150 ft thick and contains at least three thin vitric airfall ash beds of rhyolitic composition which have K/Ar age dates of about 3 m.y. and large mammal paleontologic ages of Blancan (5-2 m.y.) age. (Scarborough, 1974; E. Lindsay, pers.comm., Jan. 1981). The ash beds are undevitrified in places, but altered to clay-zeolite assemblages in others. They appear not voluminous enough or altered enough to account for the amount of uranium in the area.

Other radioactive occurrences in Pliocene-Pleistocene fine-grained sediments are noted in the San Pedro Valley east of Tucson at the Xmas and Half Moon claims (Pima County), in marly sediments around Cottonwood, Verde Valley, and in northern Mohave County at the Dreamer, Wharton, Dab, and Sunset claims. All of these appear to be local, low tonnage and grade concentrations of oxidized uranium minerals. Similar mudstone-diatomite-green chert assemblages near the Gila River around Duncan, Greenlee County, contain slight anomalies (A. O'Neill, pers. comm. Jan.1981), but are not plotted for this report.



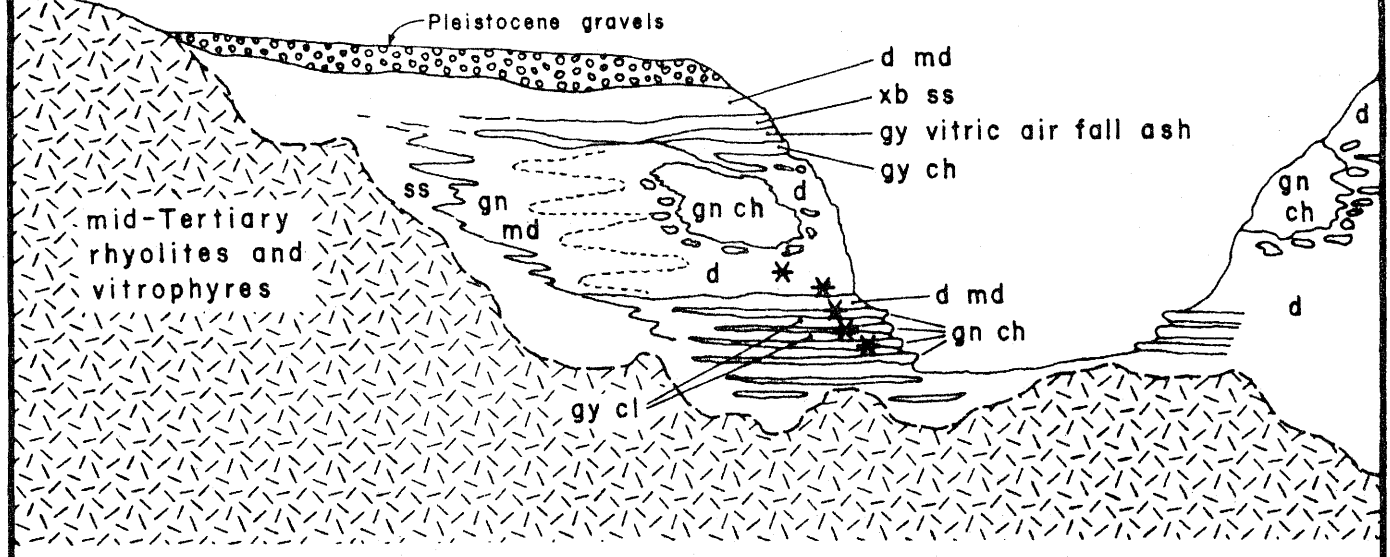
Pliocene Paludal Uranium occurrences

111 Ranch area, Graham County

Figure 34

White Bluffs Claim

Looking south
in NW 1/4 NE 1/4 NE 1/4 sec 33, T8S, R28E.
25–35 ft. of section represented,
see figure 34 for location



* – radioactive beds 2–6x

gn – green

gy – gray

d – white diatomite

d md – diatomaceous mudstones

ss – sandstones

ch – massive chert beds with concoidal fractures

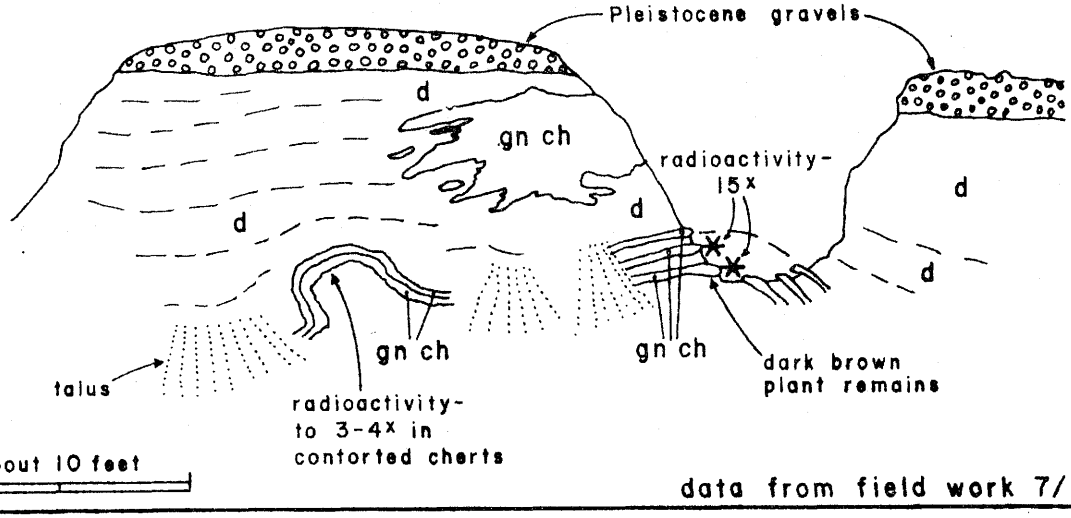
cl – claystone

md – mudstones, gray-browns

xb – cross-bedded

about 100 feet

Look south, same general area



about 10 feet

data from field work 7/80 RBS

Radioactive Pliocene Paludal–Lacustrine Rocks, 111 Ranch Area, N. Whitlock Hills, Graham County

Figure 35

Miocene Rocks in the Date Creek Basin, Yavapai County

The largest known uranium reserves and resources in Arizona at this writing are in the Date Creek Basin of Western Yavapai County. Reserves of at least 30 million pounds of U_3O_8 and resources of probably at least twice that amount have been projected for that part of the basin in the general area of the Anderson Mine. Current resource estimates indicate minable uranium ore with cutoff grade of 0.02% U_3O_8 utilizing an average grade of 0.05% U_3O_8 and average thickness of ore zones of about 20 feet. Uranium distribution in these reserves is such that average grade increases to 0.12% if average mined-thickness decreases to 6 feet, but total tonnage drops to 48% of the above amount (Sherborne et al, 1979).

Our understanding of the Cenozoic geology of the basin has been much improved by recent ongoing studies by the NURE program and the USGS, but understanding of the real extent and style of Miocene regional tectonics which has served to complicate the distribution of rocks in the region has yet to be realized.

The geology and uranium deposits of the Date Creek Basin are discussed by Otton (1977a and b) and Sherborne and others (1979). An earlier account of manganese mineralization in Miocene sediments in the area was given by Lasky and Webber (1949). See also a summary article in Engineering and Mining Journal for January, 1978.

The uraniferous sediments at the Anderson Mine are contained in a section of tuffaceous, locally carbonaceous paludal-lacustrine mudstones, calcareous mudstones, sandstones, and siltstones with some silica (chert) as pods, stringers, and plant root replacements. Two zones of uraniferous sediments are known in the Anderson Mine area, the upper one being the focus of mining activity during 1955-59 when 10,700 tons of ore assaying 0.15% U_3O_8 and at least 0.05% V_2O_5 were removed. See Figure 37 for a cross section of the area.

The Cenozoic section in the Anderson Mine region was deposited on a surface cut into a gneissic and granitic terrain of mostly Precambrian age. The Cenozoic rocks consist, in ascending order (See Figure 36 and 37), of an older sedimentary section which contains Eocene plant remains (J. Otton, pers. comm., 1980); a volcanic section called the Arrastra volcanics, composed of silicic to intermediate rock types with ages of roughly 25-20 m.y.; the uraniferous quiet-water Anderson Mine rocks and some overlying sandy beds, both probable equivalents to the early to middle Miocene-aged Chapin Wash Formation exposed farther west; an overlying 13 m.y. old alkali olivene basalt flow; and two sedimentary units of late Miocene through Pliocene-Pleistocene age. Hence the uraniferous rocks are roughly 20-13 m.y. of age.

All the above rocks up through the uraniferous Chapin Wash equivalents are repeated a number of times along a series of dominant NW-trending faults, movement along which has served to impart moderate SW dips to these strata.

The units above the 13 m.y. old basalt flow are essentially undeformed (see Figure 36). The uraniferous horizons at the Anderson Mine contain these SW dips and are last seen at the surface dipping into the main mass of the present-day Date Creek Valley. As seen in Sherborne and others (1979), the present uranium reserves are known only by drill holes that intercept the ore horizons at increasing depths to the southwest. DOE-sponsored deep stratigraphic test drilling in the main part of the Date Creek Valley has encountered uranium shows at depth that are included within sedimentary packages believed to be equivalent in age to the Miocene Artillery Peak and Chapin Wash Formations of the Artillery Peak area (see DOE report GJBX-86(80) for drill hole locations and logs).

It is important to realize our lack of understanding of the original geographic extent of sedimentary facies conducive to uranium localization. We understand approximate limits of preserved potential uraniferous strata where they occur in outcrop. But to envision boundaries of original deposition for the favorable rocks of Anderson Mine type as being limited to the present confines of the Date Creek Basin does not seem justifiable. This is because the geologic event that produced the arches of gneissic rock now present in the Harcuvar-Buckskin Ranges (present southern boundary of Date Creek Valley) appears by new regional geochronologic information to have postdated the deposition of the Anderson Mine beds. Hence, subsurface exploration should not be confined to the present Date Creek Valley. For discussion of the complexities of these Arizona "metamorphic core complexes", see Rehrig and Reynolds (1977), Davis and Coney (1979), Reynolds (1980), and Crittenden and others (1980).

Otton (1977b) and Sherborne et al (1979) both recognize two kinds of ore, or near ore-grade uranium mineralization, in the Anderson Mine area. The first is in carbonaceous siltstones and mudstones with minor silicification, and the second is in highly silicified, oxidized tuffaceous (?) siltstones with abundant megascopic plant debris. Uranium in the carbonaceous ores occurs as a urano-silica complex, close to coffinite in composition, either in microveinlets or totally disseminated (with homogeneous audoradiographs) in organic-rich siltstone (Otton, 1977b). In the oxidized, near surface regime, uranium occurs as very fine-textured carnotite with hematite in jasper pods, or as uraniferous silica in massive jasper, or in small silica veins. In less silicified ore it occurs as carnotite cement. Hence, some uranium species were fixed contemporaneously with a silicification episode, which appears to be at least in part subsequent to the original presence of the uranium in the carbonaceous ores.

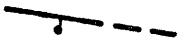
The uraniferous section at the Anderson Mine area is generally enriched in U, Li, B, Cu, F, V, Mo, and Ni. The carbonaceous ores generally are enriched in U, Ag, As, B, Cu, Ga, Ge, Ti, and Mo. Some of these enrichments are similar to examples on the Colorado Plateau, where Cu, U, or U-V mineralization occurs with Ag-Mo-Ni accessory minerals.

Several possibilities exist for the sources of Date Creek Basin uranium: (1) the anomalously uraniferous Precambrian granitic terrain adjacent to the Miocene depocenter in the Artillery Peak region (Otton, 1977a), and which was presumably exposed and eroding during the Miocene, (2) extensive leaching of the associated Miocene alkalic volcanic flows, tuffs, and ash beds - some of the coeval high-potassic volcanic rocks in the region contain 10-20 ppm by weight of uranium; and (3) a more remote possibility might be the leaching of alkalic Jurassic volcanic rocks that form a WNW-ESE swath through extreme south-central Arizona. Rocks of this affinity contain uranium occurrences in Santa Cruz County, and extend an unknown distance northwest towards the Blythe-Parker region. Possibility (2) appears most popular at this time, although the sparcity of anomalies in Cenozoic volcanic rocks is noted in the section on Cenozoic volcanics.

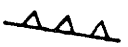
See discussion in the next section concerning possible temporal analogs of the Date Creek Basin uraniferous deposits.

Explanation for Anderson Mine general geology, Figure 36

Qs	Quaternary sediments
Tb	Miocene basalts, exact age uncertain
Tby	9-10 m.y. old undeformed basalt flows
Tcb	13 m.y. old Cobweb basalt, faulted and gently folded
Tsy	Miocene sediments, containing 13 m.y. old Cobweb basalt
Ta	Miocene Anderson Mine Fm., and, to the west, Artillery and Chapin Wash Fms.
Tva	equivalent age volcanics
Tv	Oligocene Arrastra volcanics of Sherborne, et al, (1979)
Ts	basal Tertiary arkoses and tuffs
Pzs	metasediments involved in low-angle Miocene dislocation.
MTgn	Mylonitic gneisses
pEgn	Precambrian gneissic rocks
pEg	Precambrian granite



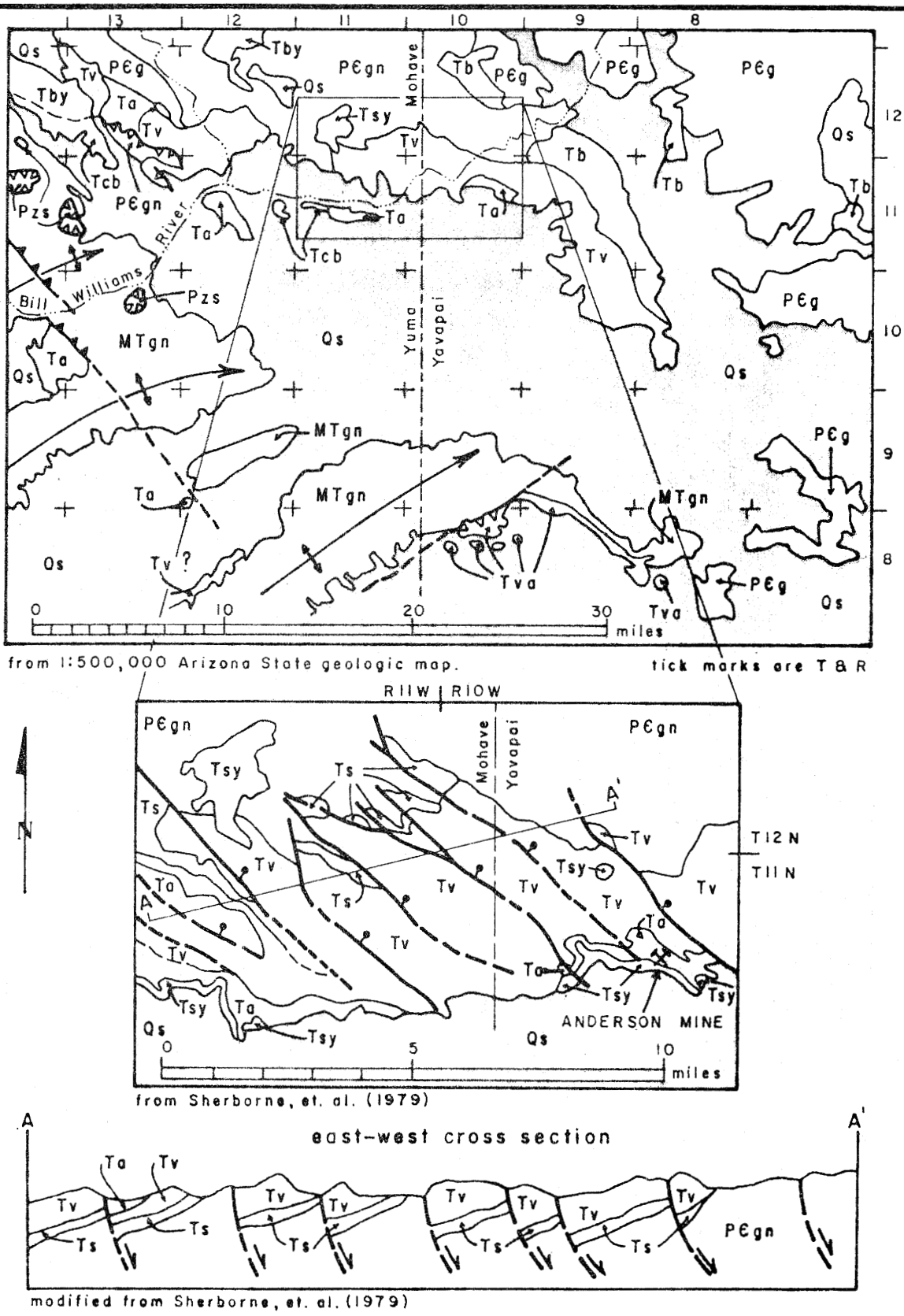
curviplanar, or listric Faults, dot on hanging wall



low-angle faults adjacent to MTgn masses, movement in mid-Miocene time, barbs on upper plate.

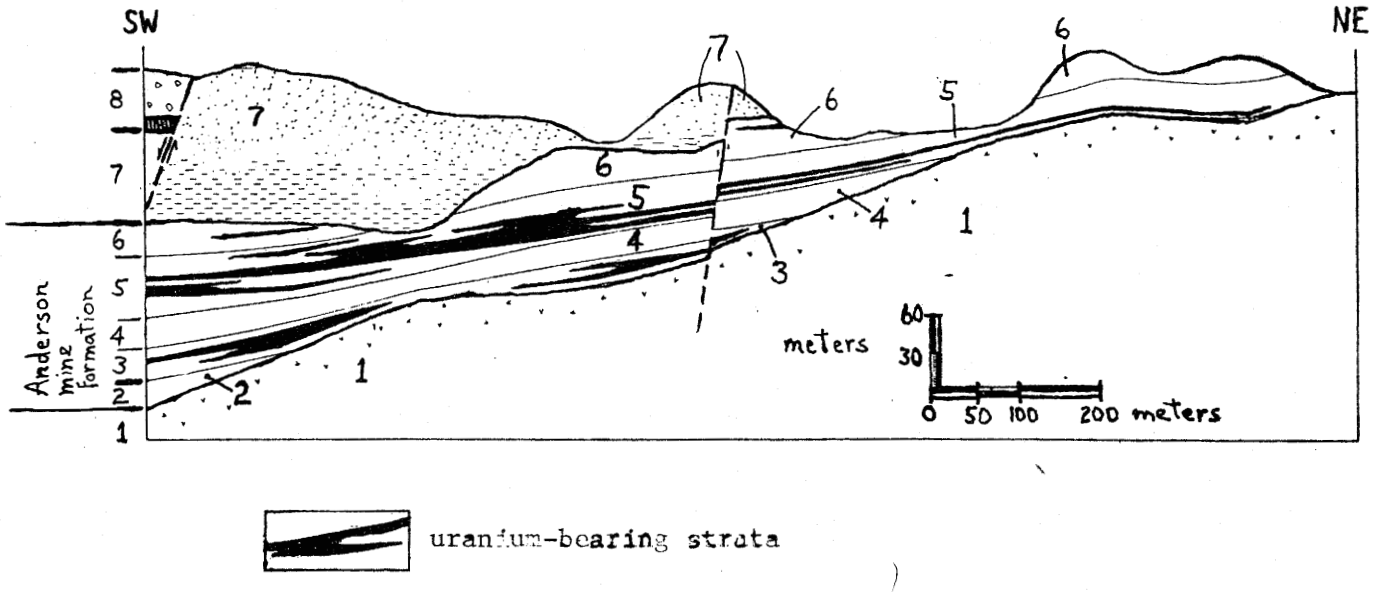
NW trending, SW vergent thrust faults, mid-Miocene age, barbs on hanging wall.

dome developed in MTgn in Miocene time, characteristic of the "metamorphic core complexes."



General Geology of the Anderson Mine area, Northern Date Creek Basin, Yavapai, Yuma and Mohave Counties

Figure 36



uranium-bearing strata

8 basalt and agglomerate (basalt is 13 m.y. old)

7 Flat Top formation

Anderson mine formation

upper mbr.

6 upper tuff and carbonate unit

5 upper carbonaceous unit

4 intermediate clastic unit

3 lower carbonaceous unit

2 lower Anderson mine member

1 Oligocene Arrastra volcanics (about 22-26 m.y.)

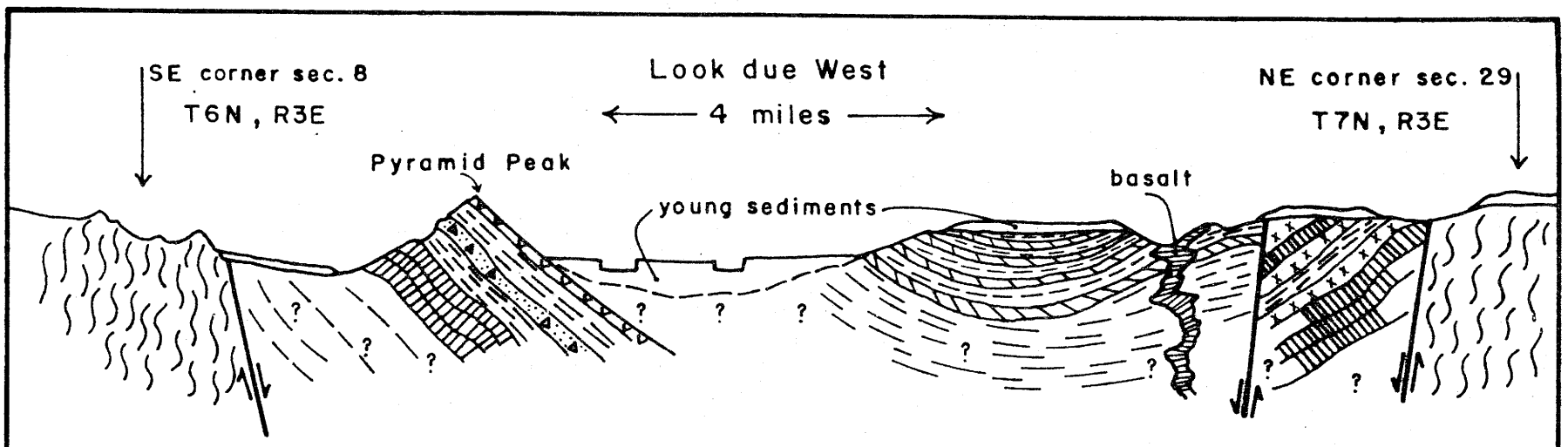
Figure 37. Southwest-northeast trending cross-section of uranium-bearing interval in the Anderson Mine area, from Sherborne and others, 1979.

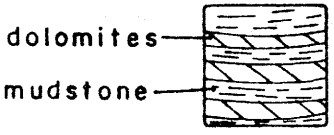
Miocene Dolomite - New River Area, Maricopa County

A volcanic-sedimentary section of early-middle Miocene age in the New River Area of Maricopa County is depicted in Figure 38. It was prospected in the 1950's as the Los Cuatros claims, and has received renewed exploration interest with some drilling in the late 1970's. The section is exposed beneath late Cenozoic terrace deposits in a valley floor, and is in high angle fault contact with Precambrian granites and schist around the perimeter of the valley.

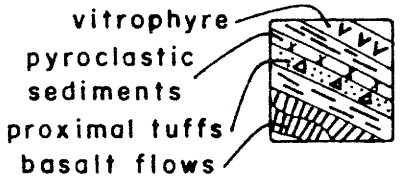
One part of the Cenozoic section consists of interlayered one-to-two foot thick light-colored aphanitic dolomite beds and buff-colored laminar bedded mudstones. Unconventionally, the dolomites are radioactive and assay 0.02 to 0.08% U_3O_8. The uranium, upon autoradiography and X-ray diffraction analysis, is randomly diffused throughout the massive dolomite, and is lacking any sign of concentration in the mudstones or sparce thin interbedded distal air-fall tuffs that are still vitric in places, altered in others. At the Los Cuatros locality, considerable tonnage of low-grade ore (about 0.03-0.06% U_3O_8) is suggested by the geology of Figure 38.

Interestingly, strata of similar age in other areas nearby (Cave Creek area and Rifle Range Section occurrences in Maricopa County listing; and in New River Mountains in cliffs on west side of Cave Creek), also contain very similar-appearing dolomitic rocks. The dolomites are known to be radioactive in the first two occurrences listed. Hence, an originally extensive areal distribution of these strata appears likely. Subsequent to Basin and Range faulting, they are now found both in range blocks and downdropped valley blocks in the region. Their subsurface distribution is not known. Age constraints on these rocks as reported by K/Ar dating results reported in Scarborough and Wilt (1979); are roughly 17-13 m.y. This time range corresponds to about the last half of the massive mid-Tertiary volcanic pulse (Cordilleran "igimbrite flare up" of Coney, referenced in Coney and Reynolds (1977), and described in Eberly and Stanley (1978). These middle Miocene ages are similar to the ages of the uraniferous units of the Date Creek Basin, which probably range roughly from 20 to 13 m.y. (Otton, 1977b; Scarborough and Wilt, 1979). Hence, from geochronologic information now available, it appears that this time during which the massive mid-Tertiary volcanic pulse of the southwestern United States was slowly shutting down, was also a time of mobility and fixation of uranium in sedimentary sumps in the central and west-central portions of Arizona. The fundamental question of the ultimate source of uranium and the role played by the massive mid-Cenozoic volcanic event in uranium mineralization remains unanswered. Positive evidence will come as more Cenozoic volcanic rocks in appropriate regions are checked for uranium depletion relative to thorium, to see if these rocks are indeed uranium depleted. Distal air-fall tuffs, when mixed into volcanoclastic sediments, may contribute appreciable uranium to the environment while losing much of their identifiable character, making them a "hidden source".





Upper (?) sequence of interbedded aphanitic dolomites and buff colored mudstones, folded into a shallow eastward-dipping syncline, and intruded by 13 m.y. old basalt dikes. Dolomites assay 0.02–0.06% U_3O_8 and count to 25 times background.



Older (?) mid-Miocene sequence of basalt flows, proximal air-fall tuffs, vitrophyres, and minor interbedded clastic sediments.

Older Precambrian Yavapai Schist, composed of metasediments.

data from Scarborough and Wilt (1979)

Los Cuatros PRR locality, New River area, Maricopa County

Figure 38

Mineta Formation - Rincon Mountains

The Mineta Formation is an Oligocene-aged sequence of mixed clastics and thin bedded limestones, 1,000 to 2,000 feet thick, and is contained in a NW-SE elongate, fault-bounded block on the NE flank of the Rincon Mountains, Pima and Cochise Counties. The section is well exposed, and dips homoclinally 15-40° to the northeast. Figure 42 idealizes the general geology and shows the general Mineta Formation stratigraphy as envisioned by Clay (1970) and Thorman and others (1978). The tectonic event that tilted the Mineta section occurred largely before the extrusion of an andesite mass, dated at 27 m.y. (Shafiqullah and others, 1978), that unconformably overlies the tilted beds.

The Mineta Formation consists of lower conglomerates containing shale lenses, middle vari-colored laminar-bedded shales and thin-bedded fossiliferous fetid limestones, and upper gypsiferous mudstones. Numerous radioactive anomalies occur over a strike length of five miles, in the following lithologies: (1) in white-to-gray thin shale lenses within the basal gray and red colored conglomerates, at the North Chance claims; and (2) in various light-colored shales or in fetid limestone beds of the middle unit, at the Center and East Chance claims; especially very near boundaries of beds where permeability changes abruptly. See Figure 42 for stratigraphic data on these locations.

Several uranium occurrences are known in complexly faulted rocks just upslope from the Mineta Formation outcrops. These include the Blue Rock claims (Pima County) and Robles Spring claims (Cochise County). These radioactive occurrences could have served as sources for uranium in the Mineta Formation, as could disseminated pods of radioactivity in Precambrian granites just upslope from the North Chance claims. However, there is no assurance that the structurally controlled occurrences in the older terrain formed before the Mineta Formation occurrences. They could all be part of a single mineralization episode.

Although some preliminary exploration work has been done in the Mineta Formation, the discontinuous nature of the radioactive outcrops and the steep dips of the formation discourage development. Potentially, however, similar rocks could underlie large areas of the adjacent San Pedro Valley at shallow depths, particularly since radioactive shales are noted in equivalent-aged sediments 10 miles east on the west flank of the Galiuro Mountains (Teran Basin occurrence of Cochise County).

Precambrian Sediments and Unconformities

As mentioned by Waechter (1979) several interesting radioactive occurrences in southern Arizona are found at or very near the contact between the base of the Pioneer Shale of the younger Precambrian Apache Group (with basal Scanlan Conglomerate missing) where it was deposited on Precambrian granite. The radioactivity appears associated with "silicified" red shales or "micropegmatites" or minor shear zones near the contact. Sometimes the red shales appear as small masses or pods within uppermost outcrops of granite. These occurrences are the Dutch Boy, Hammes, Hardrock, and Lonesome John claims of Gila County, and very possibly at the Red Hills claim in the southern Rincon Mountains near Tucson, Pima County. Other individual occurrences in Gila County (Bee Cave, Granite claims) have similar attributes, but with other modifications. None of the above occurrences except Bee Cave have any record of uranium production. Bee Cave shipped only one small shipment of "no pay" ore (i.e., assays less than 0.10% U_3O_8).

In a recently completed report by P. Anderson (GJBX-33(81), sediments of the Ader, Mazatzal, and Apache Groups of central Arizona were examined for uranium potential. Mild anomalies were located in the Mazatzal sediments associated with specularite and pyrite, and in sandstones and conglomerates of the Apache Group. Anderson attributes the lack of uranium in these sediments to their pervasively oxidized state and an absence of favorable and nearby Archean source terrain.

NON-STRATABOUND OCCURRENCES

Precambrian Granites

Radioactivity dispersed in granites of Precambrian age in southern Arizona has been recognized since the late 1940's when the first AEC reports covering the Basin and Range country were published. Anomalies disseminated in Precambrian granites, for example, are noted at the Diamond Head claims of Pima County and the Gypsy Queen, Malapai No. 1, and Valcarce claims of Maricopa County (among others).

With our increased understanding of ages of rock units as determined by isotopic dating techniques, new time-space patterns of uranium distribution in igneous rocks are emerging. Malan and Sterling (1969) summarized an AEC project that sought "exploitable uranium resources" in the Precambrian of the United States. They concluded that of the four geochronologic subdivisions of the Precambrian of the Western United States in use at that time, the highest uranium and thorium contents (4.4 ppm and 32.4 ppm respectively) were found in the 1.35-1.50 b.y. old granite suite. They also noted an apparent geographic east-to-west increase of uranium and thorium content of granites from New Mexico to southern California, with virtually all of the 21 bulk samples with statistically anomalous U-Th values coming from west of the 112° meridian (near Phoenix). This spatial arrangement of anomalies led them to propose that these rocks, present in the Mogollon highlands in Mesozoic time, was a possible source of the uranium now found in the Colorado Plateau stratabound deposits. Their preferred model of mineralization is transfer of uranium in Precambrian basement into parent magmas of Triassic-Jurassic volcanic rocks whose pyroclastic components were mixed with the Mesozoic clastics and supplied leachable uranium to the sedimentary environment.

Carlisle and others (1980), in a study of uranium mineralization of the Proterozoic sediments of the Kingston Peak Formation of the Death Valley region of California, examined the possibility of derivation of the sedimentary uranium from the anomalous crystalline rocks of the underlying World Beater crystalline complex. These rocks consist of older augen gneisses (age of about 1.8 b.y.) that contain 2.9 ppm uranium and 49 ppm thorium, intruded by a 1.35 b.y. old porphyritic quartz monzonite that contains an average of 27 ppm uranium and 70 ppm thorium. In the region, older metamorphosed sedimentary and crystalline assemblages of 1.7 b.y. age contain only a very few mild radioactive anomalies. Clearly, the 1.4 b.y. old quartz monzonite is the most uraniferous of the Precambrians crystalline rocks of the area.

Silver and others (1980) suggest that the uranium content of primary zircons in igneous rocks is a measure of the overall uranium content of the host rocks. Using this assumption, they have defined a regional uranium anomaly in the Precambrian basement rocks directly beneath that part of the Colorado Plateau which contains all of the major sandstone uranium districts (see their Figure 4, p.31). They have also applied U-Th-Pb isotopic systematics to three granites in Southern Arizona that date at 1400-1450 m.y. and

found evidence of significant uranium loss relative to thorium and lead in two of the three. These are the Ruin, Lawler Peak, and Dells Granites. Sampled parts of the Ruin Granite (Globe-Lake Roosevelt region, Gila County) have lost up to 60% (6 gm./ton) of their original uranium endowment probably within the last 75 m.y. Now, the Ruin Granite samples contain near-average crustal contents of uranium and thorium. The Lawler Peak Granite (Bagdad Mine area, Yavapai County) has lost 25% of its uranium during or since two geologic "events" at 230 ± 10 and 75 ± 25 m.y. This amount of loss, calculated for a reasonable volume of weathered granite, can account for the release of 100,000 metric tons of uranium into the environment. The Dells Granite (Prescott-Chino Valley, Yavapai County) is one of the most radioactive granites identified in the Southwest, as seen in the airborne radiometric surveys depicted in Figure 8 of Silver and others' paper. It is an equigranular two-mica granite, relatively massive and structureless, and contains about 39 ppm U and 31 ppm Th. Curiously, this very radioactive rock is in good isotopic equilbrium and has lost very little of its uranium or thorium after crystallization, based on a single sample site. The two times (230 and 75 m.y.) at which uranium loss appears to have occurred in two of the samples could be related to Permo-Triassic and Laramide orogenesis and volcanism.

In a detailed study of the Lawler Peak Granite, Silver and others (1980) concluded that most of the uranium is contained in rare high-uranium minerals such as brannerite, coffinite, and thorite. The remainder is distributed in the more common accessory minerals such as zircon, sphene, apatite, etc., and along intergranular positions and microfractures.

By all evidence, the 1400 m.y. old granite suite found throughout much of southern Arizona, does contain statistically anomalous amounts of uranium. However, no important uranium occurrences are known in these rocks where obvious shear or fault control of the occurrence is absent. However, several districts in southern Arizona with uranium prospecting or some production are situated where these granites constitute all or part of the Precambrian basement. These areas include the Bagdad region, Globe-Miami, Horseshoe Dam area (lower Verde River), northern Whetstone Mountains, Blue Rock claims of Rincon Mountains, and the western Sierrita Mountains. In the last four areas, uranium occurrences are situated along large faults that juxtapose 1400 m.y. granites with younger rocks. In each case, the granite is the most likely nearby rock to serve as a source of uranium.

Fluorite is a common accessory mineral in mineralized faults and shears involving Precambrian granites and schists in Arizona (Van Alstine and Moore, 1969). Many of the uranium occurrences in granites contain accessory fluorite, as noted in the individual listings. An example of a radioactive anomaly in Precambrian granite with fluorite is in a shallow pit just east of Highway 666 in NW¼ sec 23, T11S, R26E, (Graham County) where a thin purple fluorite veinlet cuts the granite (this locality not tabulated in individual listings). Arizona's largest fluorspar mine to date is the Lone Star Mine in the Whetstone Mountains of Cochise County. Here, greenish fluorite veins up to 2½ feet thick cut Pinal Schist. Nearby, drilling programs by Kerr-McGee and Rocky Mountain Energy have probed faults and shears involving Precambrian granite, for uranium anomalies

concentrated near the present water table. Perhaps an association of Precambrian-aged fluorite mineralization with uranium is suggested in this granite-schist terrain. At the Blue Rock claims (noted above, and discussed under vein occurrences), purple fluorite veins cut the rocks near a uranium-mineralized 10-20 foot thick fault zone that has juxtaposed 1400 m.y. (?) porphyritic granite with younger sediments.

Jurassic-Cretaceous Volcanic Rocks

South-central Arizona is known to contain a complex mixture of volcanic and plutonic rocks produced during the existence of arc-style magmatic events maximized during Jurassic through Cretaceous time. For descriptions of rocks, see Cooper (1971), Drewes (1971, 1976, 1980), Simons (1972), and Haxel and others (1980). These rocks are abundant throughout Santa Cruz County, southwest Cochise County and southwestern Pima County. The bulk of the rocks are intermediate to silicic in composition, and some are alkalic in character (S. Keith, pers. comm.,1979).

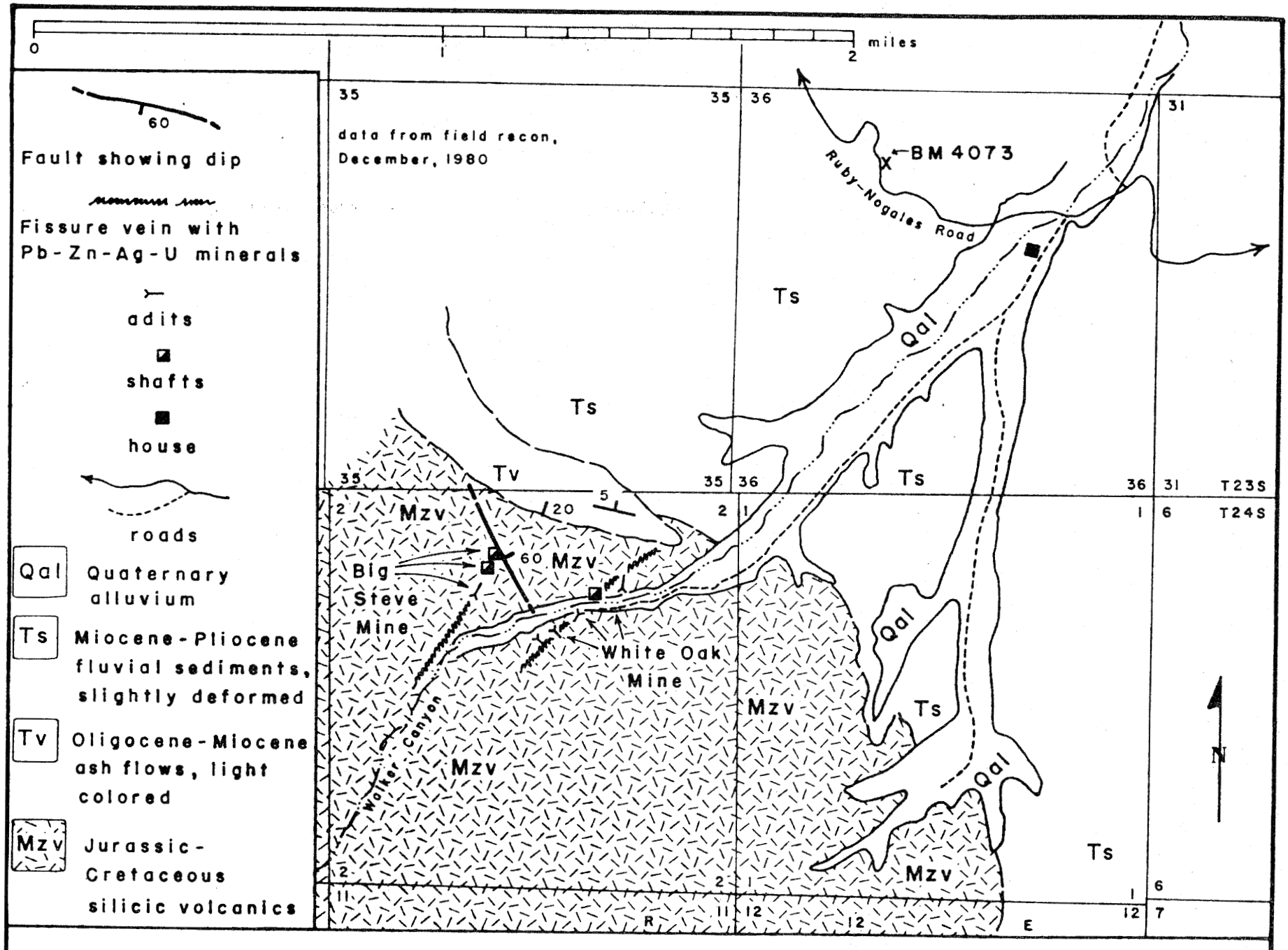
In Santa Cruz County alone, there are at least 16 known uranium occurrences in volcanic rocks thought to be of this age, including the following: Alto Group, Annie Laurie, Blue Jay, Canary Yellow, Four Queens, Happy Day and Joe Parker No. 5, Grandview Group, Happy Jack, Little Doc, Lone Star, Purple Cow, Santa Clara, Skyline, Sunset, and White Oak. Of these, minor production is recorded from two: 9 tons @ 0.28% U_3O_8 and 0.4% Cu from Santa Clara, and 18 tons @ 0.34% $U_3O_8$from White Oak. This concentration of occurrences in Santa Cruz County was first noted by Wright (1950). Figures 39 and 40 depict the geology and extent of mining at White Oak.

However, the sequence or timing of various mineralization events in this terrain is not established. The exploited mineralization in western Santa Cruz County is predominantly a Pb-Zn-(Cu)-Ag-Au vein-type with occasional uranium. However, some of the above uranium occurrences appear devoid of Pb-Zn-Ag minerals, yet appear in NE trending shears. Production from the Oro Blanco mining district (Ruby area) includes 617,000 tons of ore containing 44 million lbs of lead, 31 million lbs of zinc, 3.3 million ounces of silver, 31,400 ounces of gold, and 2.7 million lbs of copper. Many of the mineralized veins and shears strike about N50°E (see Figure 39), with a secondary NW strike component. This main strike direction and mineral association noted above is reminiscent of early Laramide (70-80 m.y.) vein systems elsewhere in southern Arizona (S. Keith, pers.comm.,Sept.1980). It remains to be determined whether the uranium was introduced with the other metals, perhaps during early Laramide time, or was more associated with earlier mineralization related to Jurassic magmatism. Since several of the radioactive occurrences are not associated with visible Pb-Cu minerals, the latter possibility is not dismissed. There is a strong relation between uranium and Cu-Pb-Zn-Au mineralization at Bisbee (Cochise County) where the base metal mineralization has been dated at lower- to middle Jurassic, and is related to the emplacement of the Juniper Flat granite there (see porphyry copper discussion).

There are a number of uranium occurrences in the Squaw Gulch-Temporal Gulch areas of the southern Santa Rita Mountains of Santa Cruz County (Figure 41), associated with limonite-stained shear zones cutting hydrothermally altered portions of the Jurassic-aged Squaw Gulch granite. See Blue Jay and Happy Jack occurrences . The nearby Ivanhoe Mine produced mostly gold, with other metals in low concentration. Drewes (1971) reports a 145 m.y. age on the Squaw Gulch granite, and maps two hydrothermally altered (Kaolinized) portions of this stock, the southernmost of which contains several radioactive anomalies.

See the discussion on Jurassic granites in southern Arizona in Drewes (1976), p. 24-29. The NURE Nogales NTMS quadrangle evaluation by Bendix suggests the Squaw Gulch area to be favorable for further exploration.

The potential for uranium occurrences in Jurassic-Cretaceous volcanic rocks remains poorly understood. For example, drill programs in the late 1970s in the Squaw Gulch area did not necessarily test the zones most favorable for uranium mineralization. And at the Happy Day claims (Santa Cruz County), several vertical shears trend N35-55°E, and display copper colors along the veins on the ceilings of two short adits driven along the veins. Early production from these veins was for argentiferous galena and copper. The same veins contain one-half inch wide black metallic crystalline uraninite-pitchblende lenses that count to 100-200X background. Several parallel shears and fractures in the immediate area also count abnormally high, yet virtually no assessment work and no drilling have been done.



General Geology Around the White Oak Mine, Santa Cruz County

Figure 39

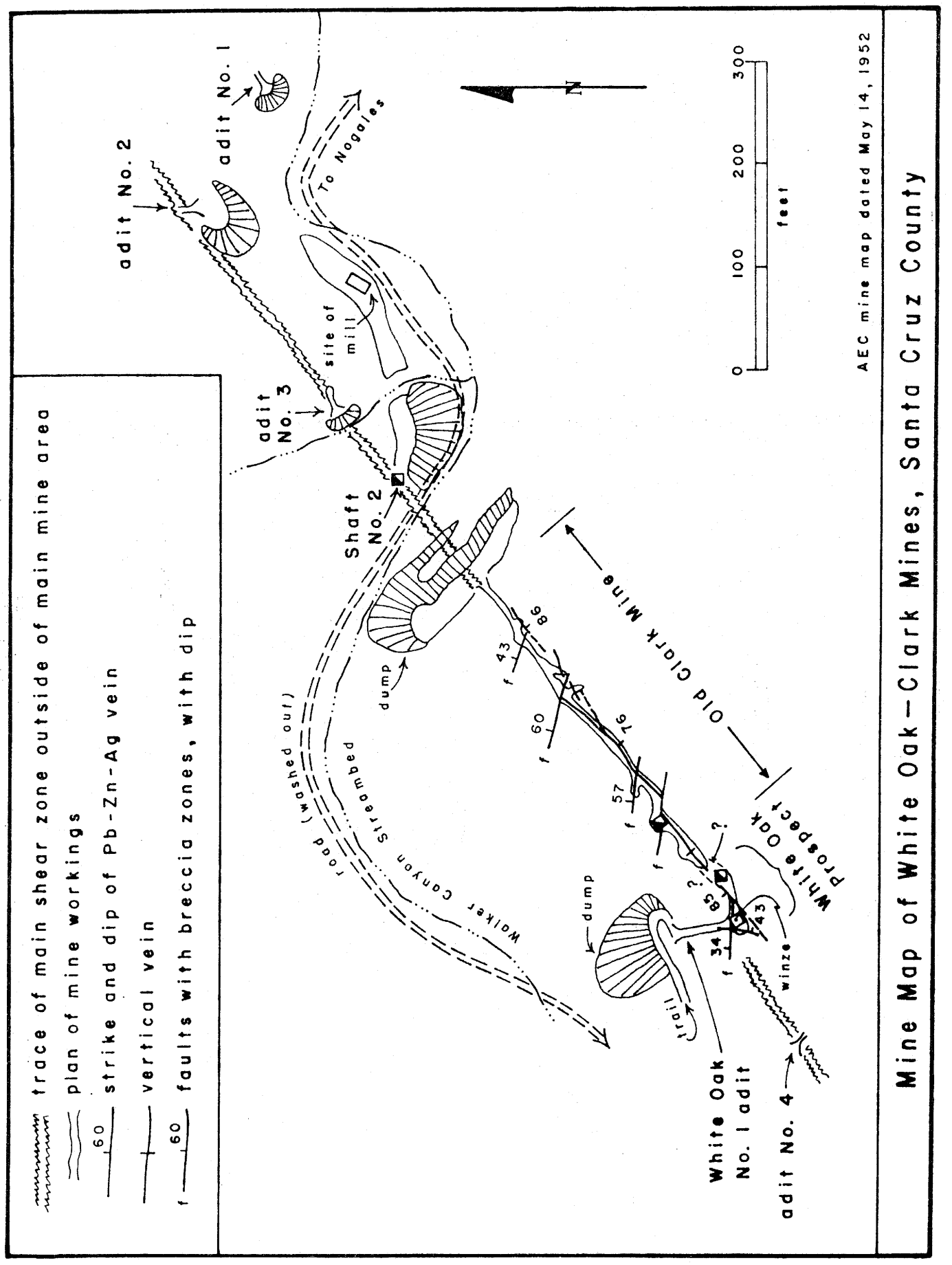
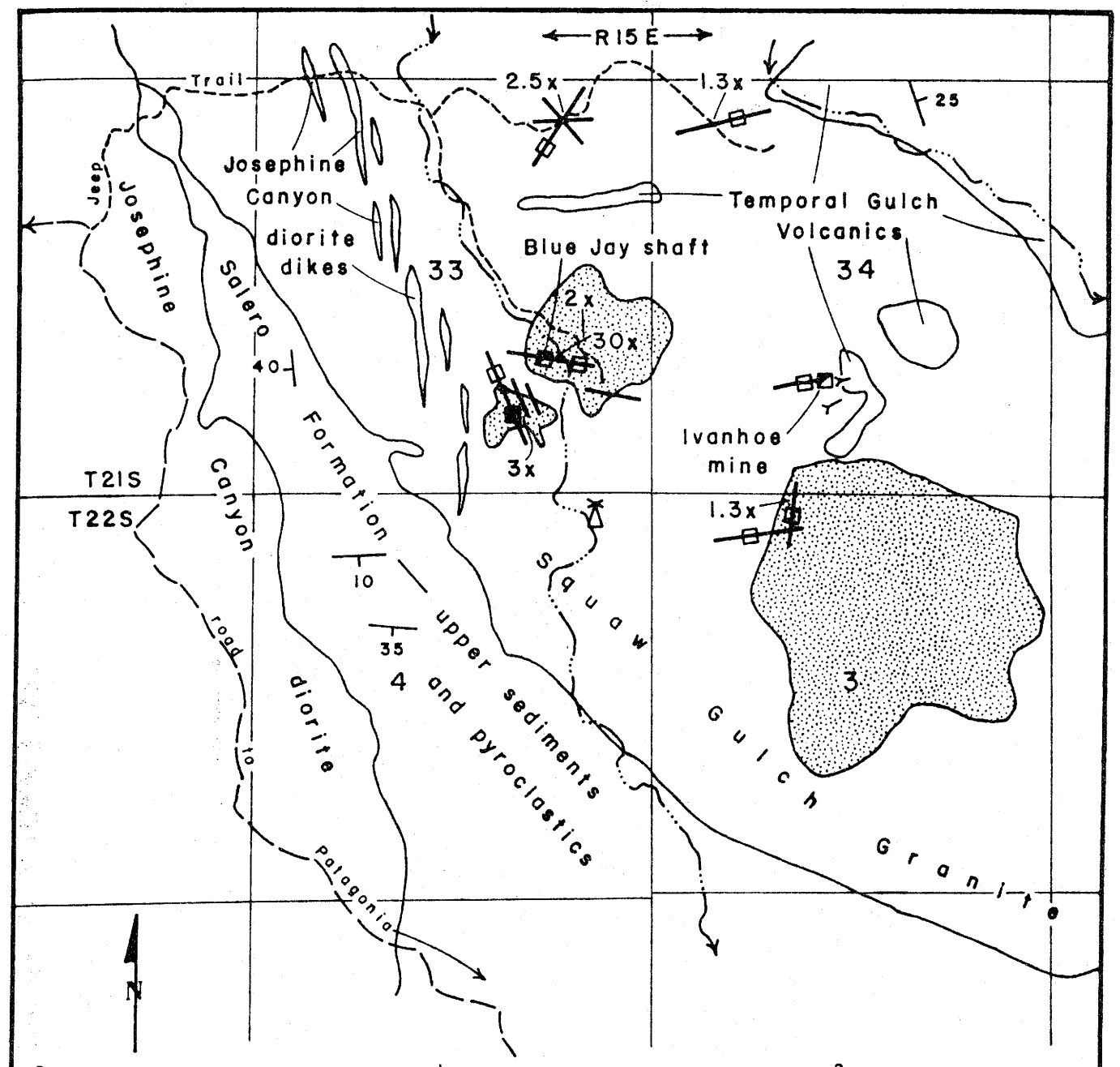

Mine Map of White Oak—Clark Mines, Santa Cruz County
AEC mine map dated May 14, 1952
0
100
200
300
feet
N
trace of main shear zone outside of main mine area
plan of mine workings
strike and dip of Pb-Zn-Ag vein
vertical vein
faults with breccia zones, with dip
adit No. 1
adit No. 2
adit No. 3
To Nogales
site of mill
Shaft No. 2
dump
road (washed out)
Walker Canyon Streambed
Old Clark Mine
White Oak Prospect
dump
trail
White Oak No. 1 adit
winze
adit No. 4

Figure 40



Hydrothermal Alteration and Uranium Occurrences, Squaw Gulch Granite, Santa Rita Mtns., Santa Cruz County

Figure 41

Porphyry Copper Deposits

The Basin and Range portion of Arizona is host to a series of calc-alkalic plutons and batholiths which are well-known for their copper and molybdenum contents. Age dates on plutonic biotite and on mineralization-related chlorites and sericites generally fall in the time range 70-50 m.y. (Titley and Hicks, 1966; Jenny and Hauck, 1978), and hence place the plutonism and related tectonics into the same general time frame as the classic Laramide orogeny first defined in Wyoming.

Besides the above metals, porphyry copper deposits characteristically contain small amounts of lead, zinc and gold. However, on a more refined scale, it appears that the ores which contain primarily Pb-Zn-Ag-Au with only minor Cu-Mo are part of a spacially related, earlier Laramide mineralization episode that was followed by the Cu-Mo porphyry pluton systems (S. Keith, pers.comm.,1981). Field evidence suggests that quite often these earlier fissure vein systems are truncated by the later plutons. Some dating evidence in southeastern Arizona suggests 75-65 m.y. for the Pb-Zn mineralization and perhaps 65-50 m.y for the Cu-Mo mineralization, with ages for both categories increasing toward the northwestern part of Arizona. In Arizona, it is the Pb-Zn systems that appear to have more closely associated uranium occurrences, rather than the Cu-Mo porphyry systems.

Some Arizona porphyry copper companies are beginning programs to extract uranium from copper leach solutions percolated through oxide dumps or mill tailings. Information in GJO-100 (80) (Statistical Data for Uranium Industry), dated 1 January 1980, suggests that nationwide, 20,000 tons of U_3O_8 will be recovered through the year 2000 from "copper dump leach liquors." Mines in Arizona at which uranium extraction is ongoing or soon to be initiated include the Twin Buttes Mine in Pima County (owned by Anamax, and Phelps Dodge's Morenci deposit in Greenlee County. Anamax has announced that first yellowcake shipments were made from Twin Buttes in May, 1980. They expect to ship roughly 120,000 lbs of yellowcake (85% U_3O_8 concentrate) per year (see "Pay Dirt" for Arizona, May, 1980 issue, and Tucson Citizen newspaper, May 1, 1980 issue). Also, uranium species have been noted at several other porphyry copper mines, such as at the Silverbell Mine, Pima County (torbernite in Oxide pit), the Copper Cities Mine, Gila County (unidentified uranium minerals in shear zones in the plutonic terrain; Still, 1962), the Ray Mine, Pinal County of Kennecott Corporation, and at the Esperanza Mine, Pima County (torbernite in altered volcanics). Detailed information on the uranium geology of these deposits is lacking. Uranium seems most abundant in association with oxidized ores, supergene-enriched areas, or vein replacements in country rock, and with shear or fault zones. Within this geologic framework, the uranium cannot be demonstrated to have been derived from the hypogene sulfide systems. It could just as well have come from other sources such as externally derived groundwaters with subsequently precipitation in the oxidized zone.

The Warren mining district at Bisbee (Cochise County), under control of Phelps Dodge Corporation, although not a Laramide, but rather a Jurassic (170 m.y. age) deposit, deserves mention. The district is now inactive except for copper leach operations, but led a colorful life as a major Cu-Pb-Zn-Au-Ag

producer from 1878 until 1975. Apparently, a concentration of uranium in the leach liquors exists that might be profitably extracted. Sketchy information indicates that concentration of uranium, along with copper, in replacement veins in country rock (such as Paleozoic limestones) is more important than uranium in the hypogene ores related to the Jurassic Juniper Flat granite or Sacramento stock. Certain of these vein systems with abundant and often spectacular azurite-malachite deposits count 2-5 times background on the scintillometer.

Bain (1952) published a 104 ± 6 m.y. uraninite age date from Bisbee , and Walker (1963) published two highly discordant ages of 175 and 1200 m.y. on similar material. These indicate some recent lead isotopic fractionation in the deposit. The Bisbee ores may prove to be a major Arizona source of uranium from the porphyry copper-type deposits. It is interesting that the Jurassic arc volcanism, which presumably produced the Bisbee ores, is somewhat more alkalic (higher $K_{57.5}$ values, Dickinson, 1970; Keith, 1978) than the Laramide porphyry copper-related rocks of the same region (Stan Keith, pers.comm,1980). Hence, an alkali-uranium relationship in plutonic terrains may suggest the feasibility of directing exploration energy towards areas having the more alkalic rocks.

The uranium occurrences of the Sierrita Mountains are an interesting example of probable Laramide uranium emplacement. Referring to Cooper's (1973) map of the Sierritas (USGS Map I-745), all the uranium occurrences in the main mountain range (Abe Lincoln, Black Dyke, Black Hawk, Diamond Head, Escondida, Glen, Hopeful, Leadville, Lena, etc.) are reported as vein-type occurrences in N70°E or N20°W fracture or fissure systems which cut a terrain dominated by pre-67 m.y. old early Laramide volcanics (Demetrie volcanics, Red Boy Rhyolite) and probable Triassic (?) - Jurassic (?) Ox Frame volcanics. These rocks are also the host for the Pb-Cu-Ag-Au vein systems of the area (Keystone Mine, etc.). This faulted volcanic terrain is intruded by the 59-62 m.y. old Ruby Star granodiorite which is thought to be related to the Cu-Mo porphyry sulfide systems of the Pima mining district. The uranium occurrences of these porphyry systems (Twin Buttes, Esperanza, New Year's Eve pit) are oxidized species (torbernite, etc.) which occur exclusively (?) in the oxide zones of these mines. The open pit mines lie under buried pediments on the lower flanks of the Sierrita Mountains, and have undergone extensive leaching, supergene enrichment, and erosional modification in their upper levels since Laramide time, much of it in the Miocene in response to Basin and Range pedimentation. Hence, with the numerous vein occurrences in the earlier Jurassic-Cretaceous volcanics upslope of this area, one may postulate either the environment of the hypogene sulfides of the porphyry systems or weathering of the upslope volcanics and vein systems as the source of the uranium minerals in the porphyry copper oxide zones.

Two Laramide porphyry copper-molybdenum systems at Mineral Park and Bagdad are discussed in the section on vein occurrences, but certainly substantiate an association of uranium with the peripheral Pb-Zn-Ag-Au vein systems of these Laramide deposits.

Cenozoic Volcanic Rocks

Although one of the more plentiful of the general rock types in Arizona Basin and Range country, the Cenozoic volcanic rocks contain relatively few uranium occurrences. These rocks range in chemistry from alkali olivine andesites to rhyolites, with voluminous latites and dacites, and volumetrically small proportions of alkali basalts and very alkalic trachytes (Shafiquallah and others, 1978).

Much attention has focused on the Anderson Mine area of the Date Creek Basin of Yavapai, Yuma, and Mohave County in the 1970's, during which time announcements were made of the discovery of at least 30 million pounds of U_3O_8 reserves (See the section on Cenozoic sediments for details). Many workers have hypothesized that this sedimentary uranium was ultimately derived from juxtaposed mid-Tertiary volcanic rocks in the area. Yet, the volcanics display many fewer surface anomalies than does, for example, the Precambrian crystalline terrain of the region. For instance, an alkalic series of flows in the Vulture Mountains, 40 miles southeast of the Anderson Mine, are devoid of uranium occurrences, as are similar-appearing flow sequences in the eastern arm of the Harcuvar Mountains, 25 miles farther west. At the west end of the Vulture Mountains, in a volcanic and volcanoclastic-dominated section, two uranium occurrences are noted in intercalated mudstones and thin-bedded limestone (Black Butte and Jar claims, Maricopa County), while the enclosing volcanics contain no known occurrences. Ten miles east of Wickenburg, a single area at the Golden Duck claims (Maricopa County) contains torbernite and other uranium minerals with chryscolla in shear zones cutting an alkali rhyolite vent complex of presumed early-middle Miocene age.

In the southeast part of the state, there are three large well-exposed volcanic centers of mid-Tertiary age; the Superstition Field, east of Phoenix; the Galiuro Field, east of Tucson; and the Chiricahua Field northeast of Douglas. All probably have larger exposed volumes of silicic rocks (rhyolites, dacites, latites) than andesitic rocks, yet have only rare uranium occurrences.

In the Chiricahua Mountains proper, a Late Oligocene, less deformed ignimbrite series (Rhyolite Canyon Formation of Marjaniemi, 1968) has a generally higher scintillometer count rate (300-500 cps with a Geometrics GR 101-A instrument over large areas) than a middle Oligocene, more deformed silicic flow series (Faraway Ranch Formation of Sabins, 1957, with 150-250 cps average readings), yet contains no known uranium anomalies in the main mountain mass. New NURE data on these two rock sequences indicate very similar K_2O contents, yet the younger rhyolites have four times the uranium content and twice the thorium content of the older rocks, based on a few field gamma ray spectrometric analyses. As well, a fluviolacustrine sequence intercalated into the Faraway Ranch silicic volcanics (termed "unknown C" in Cochise County listing) contains fetid thin-bedded limestones, and displays no anaomalous radioactivity. This would seem to hint that very little uranium was available in the surrounding volcanics for incorporation into the organic-rich sediments.

Elsewhere in southeast Arizona, a few radioactive occurrences are situated in mid-Tertiary volcanics. The Last Chance claims and the Little Swede Mine (Cochise County), about 10 miles east of Douglas in the Perilla Mountains occur

along fractures cutting a rhyolite porphyry complex mapped as mid-Tertiary in age by Drewes (1980). The Fluorine Hills and Elanna claims near Pearce, in the Sulfur Springs valley (Cochise County) are also both in faulted rhyolite-volcanic agglomeratic rocks of mid-Tertiary age, according to Drewes (1980). All these rocks are probably cogenetic with the rhyolites of the Chiricahua Mountains. The Golondrina claims (Graham County) contain radioactive pyromophite with Cu-Pb-Ag minerals in a broad N-S shear zone cutting flow breccias and agglomerates of probable mid-Tertiary age (Drewes, 1980).

In the Atascosa-Tumacacori-Oro Blanco area northwest of Nogales, it appears that the uranium occurrences there are much more confined to an outcropping altered Jurassic-Cretaceous volcanic sequence than to a moderately sized mid-Tertiary volcanic blanket, although these volcanic sequences have not necessarily been adequately differentiated on geologic maps. The fact that no uranium occurrences are known in the Cenozoic volcanics in this region, and yet many occurrences are recorded in the underlying rocks, suggests the Cenozoic volcanics are not especially uraniferous.

The uranium-beryllium-fluorine association in volcanic rocks noted in such areas as the McDermitt and Thomas calderas (Files, 1978; Wallace, et al, 1980) has not yet been recognized in Arizona, although Burt and Sheridan (1980, p.44) list two topaz rhyolite occurrences in the State, at Saddle Mountain in the southeast, and along Burro Creek, in the west-central part. Their Figure 1, p. 41, suggests that fluorine-bearing volcanic rocks are found in an area almost entirely surrounding the Colorado Plateau. This suggests that more rocks of this type may be found in central Arizona.

Vein, Fault, and Shear Zone Occurrences

Southern and western Arizona contains numerous uranium occurrences in structurally controlled positions related to quartz-rich veins, pegmatites, faults, shear or fissure zones, and along lithologic contacts in crystalline and metamorphic terrains. These occurrences appear especially prevalent in the Precambrian granite and schist terrain of Graham, Maricopa, Yavapai, and Mohave Counties, but, as seen below, often record post-Precambrian mineralization in areas where geochronology is known. This section mentions those vein-type occurrences with scattered ages and diverse geology, which do not fit neatly into the previous sections, although the Hillside Mine and Wallapai district occurrences are most likely related to Laramide mineralization.

Walker and Osterwald (1963) list 127 vein-type occurrences in southern Arizona, and give an eight-fold classification scheme into which these described occurrences are placed. In their scheme, the most numerous Arizona occurrences are in (2) base metal sulfide veins with accessory carbonates and siliceous materials, (b) veins dominated by uranium minerals (either oxidized or reduced species) with essentially no base metal shows, but with accessory geothite and pyrite, and (c) veins with fluorite and accessory barite, calcite, and silica, and occasional Pb, Zn, Cu, or Mo.

Often in shear-or vein-type occurrences, the data suggest leaching of uranium from Precambrian host rocks and its incorporation into the vein systems at the time of mineralization, such as the many occurrences in Maricopa County where only Precambrian crystalline, metasedimentary, or metavolcanic rocks are exposed over large areas surrounding the occurrences. See Altuda, Arrowhead, Bickle and Manley, Copper Kid, Dale-Compton, Lucky Find, Napsack, and Red Rover claims in Maricopa county for examples of these occurrences. Often the time of mineralization at Precambrian host occurrences is unknown. The Big Load and Stony Peak claims in Stockton pass of the Pinaleno Mountains, Graham County, record uranium concentration along large-scale N50° W faults and in attendant spring waters. Here the only country rocks for several miles are Precambrian granitics and gneissic rocks. And at the Red Rover mine of Maricopa County where considerable copper and silver with minor gold was mined out of fissure zones in Yavapai Schist, there is no obvious evidence for the time of mineralization.

Perhaps the greatest concentration of vein-like uranium occurrences in the state is in the Wallapai mining district of the Cerbat Mountains. Here, an extensive NNW trending series of veins, mined for Pb-Zn-(Cu)-Au-Ag and with thick lenticular masses of gouge also contain many radioactive anomalies, although no uranium production is recorded. The host rocks are various Precambrian crystallines, but the veins are contiguous with the Laramide Mineral Park porphyry copper pluton system, and contain evidence of geochemical zoning with respect to that system. Eidel, et al (1968) suggest that the Pb-Zn-Ag vein system constitutes the last of three stages

of hydrothermal mineralization related to the Mineral Park porphyry Cu-Mo system. See also Thomas (1949) and Dings (1951) for descriptions of mineralization studies of the Wallapi district. Damon and Mauger (1966) dated the Mineral Park porphyry at 72 m.y. by the K/Ar method.

The Hillside Mine of Yavapai County exploits a N-S trending sulfide vein system with an associated fault system (Anderson, and others, 1955) for 2,700 feet of outcrop length. Production between 1887 and 1956 amounted to 6.50 million lbs of Pb, 3.30 million lbs of Zn, 1.31 million oz. Ag, 58,700 oz. Au, and 0.40 million lbs of Cu. The mineralization is most likely Laramide in age, and is associated with the nearby Laramide Bagdad deposit. Nearby, massive sulfide mineralization associated with Precambrian volcanism in the Bagdad area consists of pyrite-chalcopyrite-sphalerite (S. Keith, pers.comm., 1981), but appears to lack radioactive anomalies. Uranium mineralization accompanies the vein system, and Anderson, et al, report a single company assay of 2.3% U_3O_8 from the now-flooded 700 foot level, directly down dip from uranium mineral occurrences on the 300 foot level studied by Axelrod, et al, (1951). Twenty-one tons of mine tailings assaying at 0.28% U_3O_8 were shipped from the mine in 1951. AEC personnel sampled the upper and lower tailings piles from the mine in 1959 and calculated 45,000 tons and 130,000 tons, respectively, of material assaying 0.06% U_3O_8 remains in the tailings.

An interesting example of a mineralized fault zone occurrence is the Blue Rock property of Redington Pass in the Santa Catalina-Rincon Mountains of Pima County. See Thorman and others (1978) for a geologic map of the area. As indicated in Figure 42, a 5-10 foot thick fault zone strikes NNW and dips 20-30° NE, and juxtaposes porphyritic granite of probable Precambrian age against a tectonically complex assemblage of Cretaceous clastic sediments, Paleozoic limestones, and Precambrian Pinal Schist (?). Quartz veins containing vugs lined with purple fluorite are found in the immediate area of the fault zone. Recent exploration drilling in the area has centered on this fault zone and possible others at shallow depths. Nearby, several other occurrences (see Robles Spring and Van Hill No. 5 claims) are in fault controlled positions with the same rock units present. The fault zone and its contained uranium mineralization is no older than mid-Cretaceous assuming a correct identification of the youngest faulted rocks as being units of the Bisbee Group. Still other uranium occurrences nearby are in Cenozoic sediments (see Chance claims, Pima County), which, from the present geologic setting, may have derived their uranium content from the upslope Blue Rock area. Coney and Reynolds (1980) have cited the Blue Rock occurrence as possibly associated with a "dislocation surface" related to the Santa Catalina-Rincon metamorphic core complex. They note (p.238-239) common hematite-chrysocolla-pyrite-barite-calcite-manganese mineralization associated with this class of faults elsewhere. The Pride Mine of northern Yuma County is developed in Cu-Fe mineralization along a dislocation surface and has minor radioactive anomalies associated with limonite pods near the fault (Scarborough and Wilt, 1979, p.69).

An area showing hydrothermal mobilization and concentration along shears of uranium mineralization is in Squaw Gulch of the southern Santa Rita Mountains. Figure 41, modified from Drewes (1971), indicates the geologic setting of the mineralized Jurassic (145 m.y.) Squaw Gulch granite. Two areas in the granite that show intense argillic alteration of feldspars (shown in the figure) contain numerous mild radioactive anomalies, as noted originally on the Blue Jay PRR (Santa Cruz County). These areas are also the loci of hematite - bull quartz veins following several major directions of shearing, especially E-W $\pm$ 10°, and N-S $\pm$ 30°. Radioactive anomalies are found most often in intensely kaolinized granite very near concentrations of these hematite veins, although often not in the veins. Also, the anomalies are most intense in valley floors, grading to barely noticeable along ridge crests. An old pre-1920 mining operation in the area at the Ivanhoe Mine recovered considerable Ag-Au-Pb-(Cu), yet is devoid of radioactive anomalies at the surface and on the mine dumps. Overall, the Squaw Gulch granite in the six square mile area centered around Figure 41 contains dozens of small discontinuous pockets of hydrothermal alteration not shown in the figure, some of which contain radioactive anomalies. It may be worthwhile to inquire about possible enrichment of uranium species near the present shallow water table in the area, since there are signs of pervasive anomalous uranium content at the surface. The age of this mineralization may best be gauged as Laramide based on (1) probable Laramide ages of E-W dikes found throughout the Santa Ritas (see Drewes, 1971) and noting that many pronounced anomalies in the Squaw Gulch area appear localized near E-W shears, and (2) the former presence of late Cretaceous volcanic cover over the Squaw Gulch granite (Temporal and Salero Formations, see Drewes, 1971) provides a mechanism for hydrothermal alteration of Laramide age in the area. Note also that the Duranium Mine (Santa Cruz County), 10 miles northwest of here, is in an E-W shear zone cutting Cretaceous sediments. That mine is discussed elsewhere in this report. The NURE Nogales quadrangle evaluation by Bendix personnel suggests the Squaw Gulch area is favorable for potential uranium resources.

The Black Dyke prospect of the Sierrita Mountains of Pima County was originally developed for copper on a NW-trending sheared contact between Paleozoic metasediments and Precambrian granitic plutons. The mined vein material contains uraninite, purple fluorite, and oxidized copper minerals. Eleven tons of ore shipped in 1957 averaged 0.18% U_3O_8. An additional 49 tons of "no pay" ore averaging 0.06% U_3O_8 and 0.04% V_2O_5 was shipped in 1956. Some potential for further mineralization remains. Most likely, the mineralization is Laramide in age, perhaps related to the extensive Pima mining district copper porphyry systems to the east. At least one of the mines in this district (Anamax's Twin Buttes Mine) is presently recovering uranium from leach circuits.

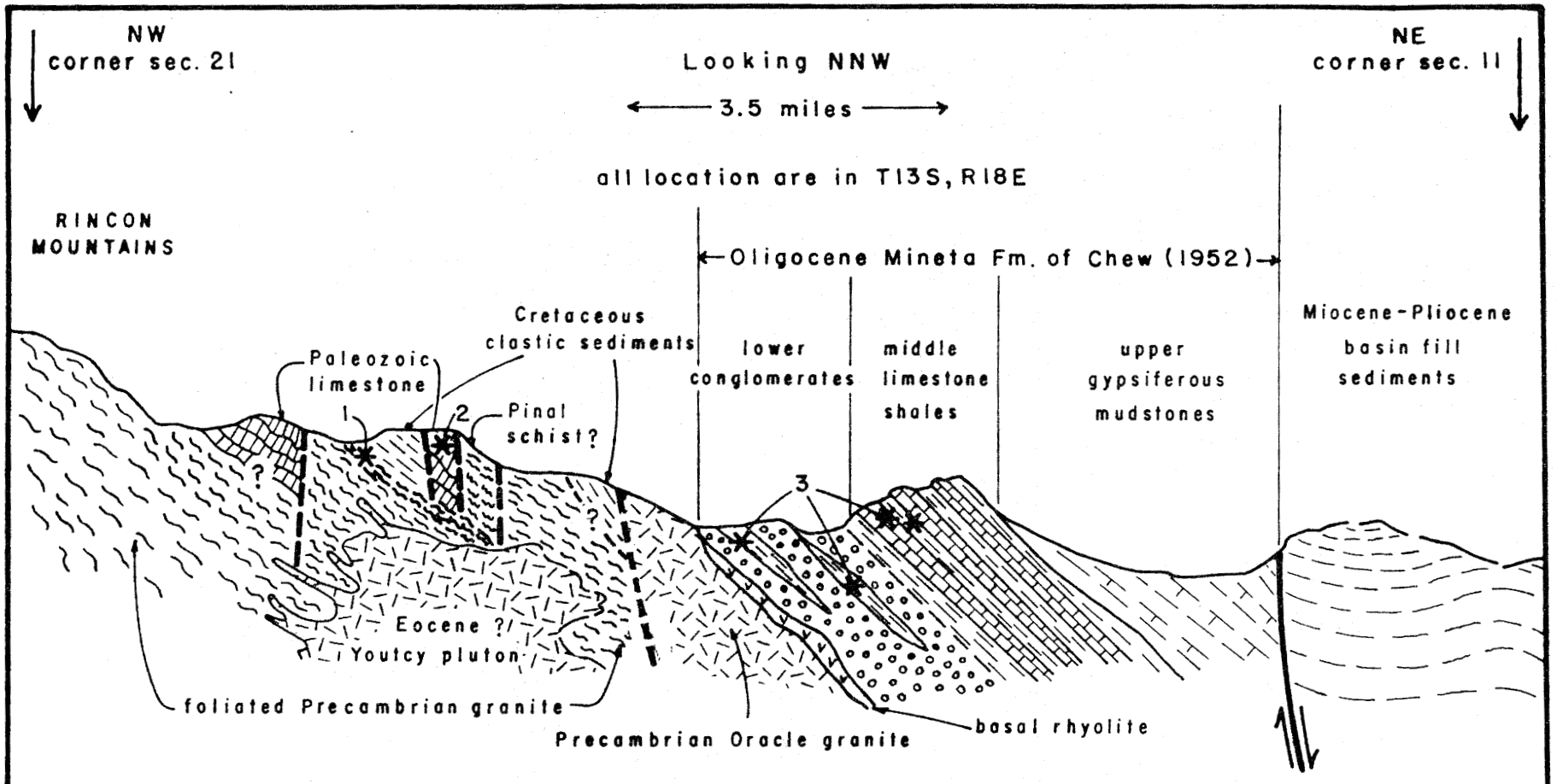


Figure 42

Idealized Cross-Section of Blue Rock, Robles Springs and Chance Claim Group Uranium Occurrences, Pima and Cochise Counties

THORIUM IN ARIZONA

Known or suspected occurrences of thorium minerals in Arizona are indicated in the geology sections of the individual listings. These fall into generally two categories, vein-pegmatite occurrences, and black placer sand deposits.

Many of the radioactive pegmatite occurrences, such as in the Aquarius Mountains and at scattered places through the Precambrian crystalline terrain of central Arizona (Yuma, Yavapai, Maricopa Counties) yield low chemical uranium analyses compared to radioactive analyses and hence probably contain thorium minerals such as euxenite, fergusonite, samarskite, or allanite. No mining of these deposits for thorium content is recorded. Staatz (1974) gives chemical and minerological analyses of two thorium vein occurrences in Arizona. The Farview claims (Yavapai County) are in a "breccia body" 100 x 60 feet across in a metamorphosed volcanic host rock, and contain rare thorite with abundant dolomite, limonite, and geothite. The Goodman Mine group of Yuma County (Staatz's Quartzite locality) has assays of up to 0.27% ThO_2 along a part of a WNW-trending shear zone which cuts Mesozoic (?) quartzose epidote schist and metasediments. He records thorite and allanite with magnetite and iron oxides from this occurrence.

The Bechetti Lease near Jerome, Yavapai County, contains a 25 foot-thick quartz vein intruding Precambrian metavolcanics and metasediments. Chemical assays on six small samples indicate ThO_2 contents of 0.2 to 1.4% and U_3O_8 contents on the same samples of 0.003-0.01%. The vein is described as containing quartz, limonite, and hematite as major minerals and is mapped for nearly 1,000 feet at the surface.

Radioactive black placer sand deposits have been noted in two environments in Arizona. These are fossil shoreline deposits related to the Mancos and Bisbee seaways of the Western Interior, and black placer sand concentrates in modern stream alluvium in the Basin and Range country of Maricopa and Pima Counties.

Cretaceous black sands of the Toreva Formation of the Black Mesa Basin are described by Murphy (1956) and Houston and Murphy (1977). They typically consist of opaque iron-titanium oxides and zircon, with minor variable amounts of rutile, monazite, sphene, apatite, allanite, niobium-bearing opaque minerals, anatase, and spinel. Radioactivity is due to variable amounts of uranium and thorium. Houston and Murphy describe three localities on Black Mesa which are thought to represent regressive beach and tide-reworked sandstones in the Toreva Formation. These deposits are 10-20 m.y. older than their geologic equivalents in the northern Rocky Mountains region.

Slightly radioactive black sand concentrates are also noted in fluvial channel deposits associated with the Petrified Forest Member of the Chinle Formation, eight miles north of Cameron, one-tenth mile east of new Highway 89.

In several parts of the Basin and Range country, modern stream alluvium containing black sands has been noted to be slightly radioactive. In Pima County, claims have been staked in the northern Sierritas (England, Will, Bixby) and in the Happy Valley area (Dollar Bill), and in the Big Horn Mountains

of Maricopa County (Black Magic). The radioactivity in these deposits is probably due to both uranium and thorium in several heavy mineral species hydraulically concentrated along the stream courses. Apparently, these placers are being derived from both Precambrian and Laramide crystalline source rocks.